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Exercise Physiology

Nutritional Adequacy and Physical Performance in Female Adolescent Hockey Players

by

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Abstract

This thesis presents research to document the physical activity, training and match demands, nutritional intake, and dietary habits in female adolescent hockey players. In Study 1, 24 female adolescent hockey player's body mass and stature were measured and developmental age calculated and compared with measures of physical performance. Participants were average developing but 90% were still growing. Physical performance measures were above population means, in line with other studies in young athletes but below elite adult female hockey players. From all measures it was concluded that adolescent female hockey players at the bottom of the England hockey selection pyramid would fit the IOC definition of an adolescent athlete. Study 2 used GPS and heart rate monitors to quantify physical demands of 45 players in U16 League Games. Distance covered and pitch time were comparable to International U16/U17 and sub-elite adult games, but the intensity of play was lower. From this study coaches working with adolescent female hockey players would be advised focus on the intensity of play in preparation for higher and adult leagues. In Study 3, 24 female adolescent hockey players completed a 4-day self-report food and physical activity diary. Total energy, carbohydrate, fruit and vegetable portions and fibre were all lower than guidelines, and saturated fat and sugar intake were higher than recommended. Protein intake was adequate but poorly distributed across the day. On the back of this data, in line with the National Diet and Nutrition Surveys (2012-2020), practitioners working with this age group should initially focus on population healthy eating advice, increasing fruit and vegetable intake and ensuring adequate protein availability across the day. Study 4 used an online questionnaire to document habitual eating behaviour and physical activity levels in 162 female adolescent hockey players. Participants played 21 different sports. Physical activity was classified as moderate overall and high in the evenings and weekends. Most participants ate breakfast and a cooked lunch, but there was evidence that eating behaviour was impacted by sports participation and this should be taken into

account when planning sports training schedules and nutrition education. Study 5 concurrently measured physical activity (accelerometer and GPS), nutritional intake (food diary), nutrition knowledge and eating behaviour (surveys) in 29 female adolescent hockey players over seven days. The regular sports training and competition contributed to players high energy expenditure, which was not matched by energy intake. Dietary quality was poor with high intake of saturated fat and added sugar and low fibre intake. In summary, the research in this thesis presents novel data on anthropometric and physiological characteristics, training and match loads, physical activity, nutritional intake, and dietary habits of female adolescent hockey players which can be used to inform evidence-based guidance for players, parents, schools, and coaches.

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Declaration of authorship

I, Matilda Jane Spurr declare that the thesis entitled
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and the work presented in the thesis are both my own and have been generated by me as the result of my own original research. I confirm that:

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- none of this work has been published before submission,

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Date:……. 20/1/22 …….

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Finally - "We have two lives and the second begins when we realise we only have one" (Confucius 500 BC). Thank goodness I saw the light.

Definitions and abbreviations

ΔST	Delta slalom time. Difference between the dribble and sprint times in the SlalomSDT test.
%	Percentage
ACL	Anterior cruciate ligament
ACSM	American College of Sports Medicine
ANOVA	Analysis of variance
APHV	Age at Peak Height Velocity
AS	Afternoon Snack
B	Breakfast time meal
BF%	Body Fat Percentage
BM	Body Mass
BMR	Basal Metabolic Rate
BPM	Beats per minute
CHO	Carbohydrate
cm	Centimetre
CMJ	Countermovement Jump
COMA	Committee on Medical Aspects of Food & Nutrition Policy
DLW	Doubly Labelled Water
EA	Energy Availability
EB	Energy Balance
EI	Energy Intake
EE	Energy Expenditure
EEE	Exercise Energy Expenditure
ES	Evening Snack
FAO	Food and Agriculture Organisation
FFM	Fat Free Mass
FM	Fat Mass
FIH	International Hockey Federation
FV	Intake of fruit and vegetables
g	grams
GDPR	General Data Protection Regulation
GI	Glycaemic Index
GNKQ	General Nutrition Knowledge Questionnaire
GPS	Global Positioning System
h	Hour
HGS	Handgrip Strength
HR	Heart Rate
HSR	High Speed Running
JAC	Junior Academy Centre Training
JASP	Jeffrey's Amazing Statistics Program
JDC	Junior Development Centre Training
kcal	Kilocalorie
kg	Kilogram
LBM	Lean Body Mass
LEA	Low Energy Availability
L	Lunch time meal
m	Meters

METs	Metabolic Equivalents
min	Minutes
mg	Milligrams
ml	Millilitres
MS	Morning snack
MVPA	Moderate-Vigorous Physical Activity
NAG	National Age Group Training
NDNS	National Diet and Nutrition Survey
NEAT	Non-Exercise Activity Thermogenesis
NK	Nutrition Knowledge
NSP	Non-starch polysaccharide
ONS	Office of National Statistics (UK)
p	Probability
PA	Physical Activity
PAL	Physical Activity Level
PAQ	Physical activity questionnaire
PC	Performance Centre Training
PHV	Peak Height Velocity
PRO	Protein
r	Sample correlation coefficient
RAE	Relative Age Affect
RED-s	Relative Energy Deficiency in Sport
RMR	Resting Metabolic Rate
RNI	Recommended Nutrient Intake
RPE	Rating of Perceived Exertion
ROC	Receiver Operating Characteristics
S	Supper / Evening meal
SACN	Scientific Advisory Committee on Nutrition
SEE	Standard error of the estimate
ShuttleSDT	Shuttle Sprint Dribble Test
SlalomSDT	Slalom Sprint and Dribble Test
SPSS	Statistical Package for the Social Sciences
SVM	Subtracted sum of vector magnitudes
TEE	Total Energy Expenditure
TEF	Thermic Effect of Food
TMA	Time Motion Analysis
UNU	United Nations University
Uni	University
W	Watts
WHO	World Health Organisation
TPHV	Time from peak height velocity
yr	Years

1. Introduction

To provide evidence-based nutrition advice for sports performance in adolescent athletes, it is key to understand the demands of the sport and how training and competition fits within other physical activity, education, and social demands. Adequate energy and nutrient intake are particularly important in this age group due to the additional needs for development and growth.

Hockey is a popular sport taught and played at many British schools and is one of the largest participation sports played at British colleges and universities (England Hockey Board, 2021). The physiological demands of female adult hockey are known to be considerable, where players carry out a range of repeated explosive actions, with high relative distances covered and multiple changes in direction (Bergeron *et al.*, 2015; Jayanthi, Pinkham, Dugas, Patrick, & Labella, 2013). It is unclear whether the movement pattens and demands are the same in the adolescent game.

A large number of girls drop out of organised sport during adolescence, the latest numbers from Sport England show 57% of 11-16yr old girls in the UK do not meet government targets of 60 minutes of physical activity a day (Sport England, 2021) and 64% of girls have been found to quit organised sport completely by the end of puberty (Proctor & Gamble, 2016). For those that continue to play, there is often increasing pressure to specialise, to train all year round and to be in a constant cycle of trials and competition (Brenner, 2016). In team sports, “cross-over” of skills from one sport to another is common (Pasulka, Jayanthi, Mccann, Dugas, & Labella, 2017) and with increased talent identification and physiological profiling, ‘promising’ young athletes, are often courted by and training for, more than one sport. This is particularly the case for female athletes as the number of adolescent girls participating declines steeply (Armstrong, 2000). In England the talent pathway, the England Hockey Single System

selects on referral from clubs and schools (England Hockey, 2020) and offers access to additional training and rounds of selection. Little is known about this group or the physiological attributes that are required to be selected. Selection is done into chronological age groups, and it is not known if this favours early or late physical developers. Adolescent girls at the same chronological age can have a different biological or developmental maturity relative to others of a similar age (Armstrong and Mcmanus, 2011; Baxter-Jones, Eisenmann, & Sherar, 2005; Cameron, 2015; Kemper and Verschuur, 1981). Biologically more developed girls may have an advantage in some physiological measures but may also be disadvantaged by having higher body fat composition (Guo, Chumlea, Roche, & Siervogel, 1998) . The increasing difference between boy's and girl's strength and speed during adolescence have been shown to be at least partially associated to changes in body composition (Armstrong and Mcmanus, 2011). In a sport like hockey that requires speed and explosive power, an increase in body mass will decrease acceleration (Keogh, Weber, & Dalton, 2003) and physiological characteristics such as aerobic and anaerobic capacity (Hogstrom, Pietila, Nordstrom, & Nordstrom, 2012). No studies have been done in adolescent hockey players but strength, power (Granados, Izquierdo, Ibanez, Ruesta, & Gorostiaga, 2008) and speed (Nikolaidis *et al.*, 2016) have been shown to be closely related to body composition among elite footballers (Gil, Ruiz, Irazusta, Gil, & Irazusta, 2007; Reilly, Bangsbo, & Franks, 2000). The physical advantages of low body mass, along with the competition and comparison with later developing girls could be a particular risk factor for dietary inadequacy in female adolescent hockey players.

Low energy availability (LEA) should be seen as a concern in female athletic adolescents as both chronic low energy intake (EI) and poor 'at the time' energy availability (EA) in adolescent girls causes impaired growth and maturation, increased injury risk and health implications later in life (Loucks, Kiens, & Wright, 2011). Nutritional needs are higher during adolescence than any other time, due to rapid growth of skeletal muscle and bone

development (Gibson, Stuart-Hill, Martin, & Gaul, 2011). Several studies have shown that junior athletes' diets are inadequate compared to both National Dietary Guidelines and Sport Nutrition recommendations (Gibson*, et al.*, 2011; Zalcman *et al.*, 2007) and a high proportion of adolescent athletes have been shown have low EI and be at increased risk for eating disorders (Bratland-Sanda and Sundgot-Borgen, 2013; Knapp, Aerni, & Anderson, 2014; Melin, Torstveit, Burke, Marks, & Sundgot-Borgen, 2014; Sundgot Borgen and Torstveit, 2010; Sundgot-Borgen and Torstveit, 2004). Negative body image is known to be a major barrier to sports participation in adolescent girls (Brudzynski and Ebben, 2010; Crane and Temple, 2015) and may be an issue within adolescent hockey players. Marshall and Harber (1996) reported that elite adult female hockey players demonstrate a high level of body dissatisfaction and an elevated drive for thinness.

The highest rates of sports injury occur during adolescence (10-14yr) (Stephenson, Kocan, Vinod, Kluczynski, & Bisson, 2021) and injury in young female hockey players, particularly anterior cruciate ligament (ACL) injuries, are common (Naicker, 2014). Injury risk has been linked to a sudden increase in training volume and poor pre-season and in-season strength and conditioning (Abernethy and Bleakley, 2007) but education, including education in hydration and nutrition also lowers this risk (Hogstrom*, et al.*, 2012). Although nutritional knowledge seems to be high among athletes (Heaney, O'connor, Michael, Gifford, & Naughton, 2011), there is growing evidence that adolescent athletes do not follow nutritional guidelines, which is likely to negatively affect their health, post-exercise recovery and athletic performance (Meyer, O'connor, & Shirreffs, 2007). Adolescence is the time at which individuals begin to have greater independence from their family in choosing what they eat (Thomas, 1991) and adolescents tend to snack and graze, miss meals, eat away from home and consume fast foods more frequently than younger children or adults (Mckinley, Oliver, & Livingston, 1995; Squire, 2013; Story, Neumark-Sztainer, & French, 2002). Very little is known about the eating habits of adolescent hockey players, whether their overall intake

is adequate or whether it meets current sports specific recommendations. Quantifying current eating behaviour is crucial to inform evidence-based strategies to support athletes. This is particularly important in this population as there are key anatomical, physiological and metabolic differences between adolescent athletes and adults (Hannon, Close, & Morton, 2020; Hannon, Unnithan, Morton, & Close, 2019) and very little research available in young female athletes that can be used to formulate evidence-based advice (Desbrow, Burd, Tarnopolsky, Moore, & Elliott-Sale, 2019).

1.1 Summary and aims

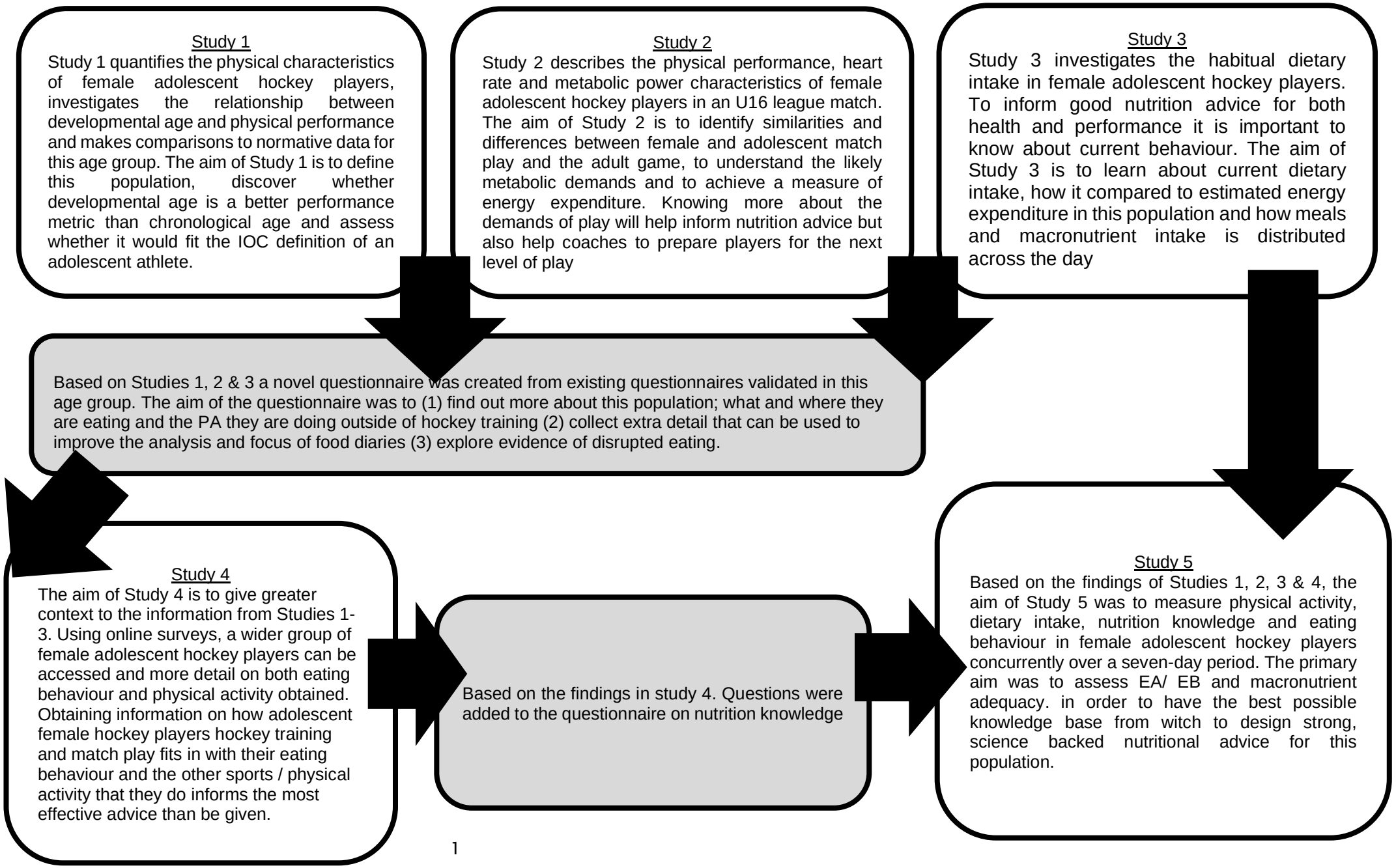
In summary, there is a lack of research examining the key physiological characteristics, level of sports participation, dietary intake, and energy expenditure (EE) in female adolescent hockey players in addition to the demands of female adolescent hockey training or competition. This thesis will aim to address these gaps in the literature and investigate the hypothesis that the female adolescent hockey player population are fitter, have higher EE and physical activity levels than population normative data, that the demands of playing competitive hockey are high and that adolescent girls are not adequately compensating for this with their current term time dietary intake.

The research to address this aim is presented in 8 chapters. The aims of each experimental study are given within Figure 1.1.

- Chapter 1 – General introduction
- Chapter 2 – Review of the literature
- Chapter 3 – Study 1 quantifies the physical characteristics of female adolescent hockey players, investigates the relationship between developmental age and physical performance and makes comparisons to normative data for this age group.

- Chapter 4 – Study 2 describes the physical performance, heart rate and metabolic power characteristics of female adolescent hockey players in an U16 league match.
- Chapter 5 – Study 3 investigates the habitual dietary intake in female adolescent hockey players.
- Chapter 6 – Study 4 examines self-reported physical activity profile, diet and eating habits in female adolescent hockey players.
- Chapter 7 – Study 5 concurrently measures and self-reported physical activity, dietary intake and eating behaviour in female adolescent hockey players over a 7-day period during the hockey season.
- Chapter 8 – General discussion, draws together the findings from the previous chapters and discusses areas for future research.

Figure 1.1 Overview of the aims of studies 1-5 within the thesis.



In this thesis the term “adolescent” will be applied to girls aged 12–18 yr and boys aged 14–18 yr in keeping with the definitions of Faigenbaum (2000) and Tanner Stages three and four of sexual maturation (Tanner, 1962). The term “child” will refer to girls and boys prior to the development of secondary sex characteristics, (Tanner Stage one and two), defined as up to the age of 11 yr for girls and up to age 13 yr for boys. The term ‘young’ is used as a general term including both children and adolescents up to the age of 18. The classification of athletes within this research have been assessed in line with the classification framework proposed by Mckay *et al.* (2022), where the term elite refers only to those competing at International level or above. The adolescent hockey players in this study were classified as being of level 2 or 3, trained/developmental or highly trained/national level.

2. Literature review

2.1 Developmental Physiology of Adolescent Athletes

2.1.1 Developmental Age

In sports such as hockey, chronological age from date of birth has traditionally been used to group athletes into age group teams or bands for competition. However, adolescent changes in somatic growth and the rapid changes in body composition, hormone levels and fat free mass are highly individual (Bitar, Vernet, Coudert, & Vermorel, 2000) and it is possible for adolescent girls at the same chronological age to have markedly different biological or developmental maturity (Armstrong and Mcmanus, 2011; Baxter-Jones*, et al.*, 2005; Cameron, 2015; Kemper and Verschuur, 1981). Individuals can be either biologically ahead of their chronological age (early maturing individual), in time with their chronological age (average maturing) or behind their chronological age (late maturing individual) (Malina, Bouchard, & Bar-Or, 2004). As chronological age is not associated with physical development, it is a poor indicator of maturity and the physiological and metabolic variables related to exercise performance and this mismatch is particularly significant at 12-15 yr, when specialisation into individual sports is at its peak (Armstrong and Mcmanus, 2011).

The onset of sexual maturation coincides with peaks in growth and changes in performance. The development of aerobic fitness increases naturally with the growth of the heart, lungs and circulatory system, and anaerobic power with greater muscle volume. Increased strength directly correlates to increased skeletal muscle hypertrophy and improvements in jump, sprint and Wingate tests have been shown to be directly related to increased leg length and muscle size (Moran, Sandercock, Rumpf, & Parry, 2017; Philippaerts *et al.*, 2006). Increased height has also been associated to an increase in leg and stride length, decreasing the necessary stride frequency at a given speed and the oxygen cost of running, whereas increased body fat percentage during maturation is detrimental to agility, speed and endurance (Rowland, 2005).

Therefore, it is important to be able to quantify adolescent athlete's biological age when judging individual performance.

During adolescence a marker of biological age or maturity can be determined by physical examination of presence or absence of secondary sex characteristics, including breast and genitalia development, pubic hair growth, facial hair, voice change, body odour, body shape and onset of menarche (Baxter-Jones*, et al.*, 2005) and comparing these with the Tanner Scale (Tanner, 1962). Tanner scaling is accurate (Baird, Walker, Smith, & Inskip, 2017) but is not easy, requiring participants to undress for examination and is consequently invasive. Although it may be possible to self-assess stages of development based on standardised photographs of the five Tanner stages (Malina*, et al.*, 2004) and this appears to have good reliability (Bond *et al.*, 2006; Chan *et al.*, 2008), female subjects have been found to overestimate early stages and underestimate late stages of development (Schlossberger, Turner, & Irwin, 1992).

As well as using markers of sexual maturity, development can be monitored by measurement of growth in height and other body dimensions such as limb length. Peak height velocity (PHV), is the time of maximum velocity of growth in stature during the adolescent growth spurt and age at peak height velocity (APHV) has been identified as a reliable indicator of maturity in adolescents (Baxter-Jones, 2007) which can be used to compare the biological maturity levels between individuals (Rowland, 1989). The chronological age at which individuals show peak height velocity (PHV) varies widely but on average in the UK it occurs around the age of 12 yr (range 9.5-14.5 yr) in girls and 14 yr (range 10.5-17.5 yr) in boys (Baxter-Jones*, et al.*, 2005). An individual who is currently within their peak growth phase will have a biological age equivalent to 0.0 yr from APHV and this value can be used as a measure of biological age to compare individuals, being classified as early, average, or late maturers. Early maturers have an APHV ≥ 1 yr before mean APHV and late maturers have an APHV of ≥ 1 yr after mean APHV, with the rest classed as average maturing (Baxter-Jones*, et al.*, 2005).

To identify when individuals are at PHV, height and growth need to be monitored over an extended period and height-change increments plotted against age in years, to determine the age at which maximal height growth change occurs. To avoid this need for regular tracking, Mirwald, Baxter-Jones, Bailey, & Beunen (2002) established a set of sex-specific multiple regression equations, based on anthropometric measurements, that predict time from peak height velocity (TPHV) using the growth patterns of height, sitting height and leg length (Mirwald*, et al.*, 2002). In girls this predictive equation (Mirwald's Equation) for the maturity offset or TPHV is given as Equation 2.1.

Equation 2.1 Mirwald's Equation for maturity offset from PHV

Maturity offset = -9.376 + (0.0001882*leg length and sitting height interaction) + (0.0022*age and leg length interaction) + (0.005841*age and sitting height interaction) – (0.002658*age and weight interaction) + (0.07693*weight by height ratio), where R = 0.94, R^2 = 0.89 and the Standard error of estimate was 0.569.

The maturity values obtained using Mirwald equations are able to predict the age at peak height velocity within a year of the measured value in 95% of individuals and within half a year in 89% of individuals (Mirwald*, et al.*, 2002). Mirwald's Equations are currently the standard non-invasive method of calculating PHV and have been found to be reliable, though there is some evidence that APHV calculated close to PHV can cause the results to skew longer (Mills, Baker, Pacey, Wollin, & Drew, 2017).

To assure the best estimate of maturity from these prediction equations attention must be paid to ensuring the measurement procedures are standardised. This is particularly important for measurement of seated height as it is related to more than one of the independent variables. Due to the errors inherent in the measurement of seated height, Moore *et al.* (2015) created

and validated alternative equations eliminating this measure. In girls, the predictive equation (Moore Equation) for the maturity offset or time from PHV is given as Equation 2.2.

Equation 2.2 Moore's Equation for maturity offset from PHV

Maturity Offset = -7.709133 + (0.0042232 x age * height (cm)); where $R^2 = 0.898$ and SEE = 0.528.

2.1.2 Relative Age Effect

Relative Age Effect (RAE) is the term used for the existence of a selection bias, that athletes born early in the selection year are more likely to be identified as talented and selected by national age group or professional teams and therefore get the training benefits that allow them to become elite players (Tier 5/4 (Mckay*, et al.*, 2022)). A clear relative age effect has been demonstrated for all the male European National Youth football teams; U-15, U-16, U-17 and U-18 age categories (Helsen, Van Winckel, & Williams, 2005) and in male ice-hockey, baseball, basketball, volleyball and hockey (Rees *et al.*, 2016). Male players born later in the selection years are found to be more likely to drop out of competitive sport (Delorme, Boiché, & Raspaud, 2010; Feltz and Petlichkoff, 1983). Studies have suggested that a RAE is less likely to be found in female teams (Lidor, Arnon, Maayan, Gershon, & Côté, 2014; Romann and Fuchslocher, 2013; Schorer, Cobley, Büsch, Bräutigam, & Baker, 2009), particularly by the age of 17 yr (Vincent and Glamser, 2006). It was suggested that this could be due to the smaller number of individuals involved, allowing selection on technical components of the game rather than the physical attributes (Sierra-Díaz, González-Víllora, Pastor-Vicedo, & Serra-Olivares, 2017) but it could also be due to there being a physiological advantage to being later maturing in female sport. Despite the advantage of increases in muscle development and power with maturity, developmentally 'younger' females who have narrow hips, slender physiques, longer legs and low levels of body fat may be at a physical advantage late in adolescence (Sierra-Díaz*, et al.*, 2017). In girls, peak weight gain lags peak height velocity by ~6 months and is approximately 8.3 $kg \cdot yr^{-1}$ during adolescence. Although height

velocity decreases after, PHV and menarche, final or adult height is usually achieved 1 yr after (Das *et al.*, 2017).

2.2 Anthropometric and Physiological Factors

There has been considerable research investigating the anthropometric and physiological characteristics of adult team sport athletes (Tier 1-5) to inform physical performance standards. However, there has been limited research in child or adolescent competitors and this research has been almost exclusively in boys (Armstrong and Mcmanus, 2011; Mcmanus and Armstrong, 2011).

2.2.1 Body Composition

Quantifying body composition plays an important role in monitoring the efficiency of athlete training and dietary regimes within team sports (Ackland *et al.*, 2012). Before puberty, there is no measurable difference in fat mass between boys and girls but the production of sex steroids during adolescence causes typical pubertal fat mass gain of 7.1 kg in girls, approximately twice that of boys (~3.2kg) (Malina*, et al.*, 2004) and after puberty the minimum level of body fat compatible with health is estimated to be 5% in men and 12% in women (Ackland*, et al.*, 2012). The most obvious effect of this difference is to limit performance in weight-bearing activities; the increase in fat-mass being an additional inert load to be carried. In 12 yr olds, fat-mass has been shown to account for up to one third of the variance in performance during a running trial (Rowland, Kline, Goff, Martel, & Ferrone, 1999) and it has also been associated with poor heat dissipation in young athletes, further lowering performance (Falk and Dotan, 2011). Gradidge and Constantinou (2017) examined the comparative performance of adolescent male and female footballers and showed that the differences in lower-limb power performance were directly linked to differences in body composition.

The average non-athlete adolescent girl of European ethnicity has been identified as having a body fat percentage (BF%) at the end of puberty of 26-31% (Sherar, Baxter-Jones, &

Mirwald, 2007). Young female athletes are generally leaner and have lower BF% than non-athletic girls of the same age (Malina, Geithner, O'brian, & Tan, 2005) and the difference between athletic and non-athletic girls increases through adolescence, non-athletic females' relative fatness increasing as a result of normal growth and development, whereas an athletic females' relative fatness remaining stable (Baxter-Jones and Mundt, 2007). This relationship has been demonstrated to continue through adulthood across 26 Olympic sports where female athletes have body fat levels well below average (Sundgot Borgen and Torstveit, 2010).

BF% in elite (tier 4/5) adult female hockey players have been reported as being between 14% and 25%, (Calo, Sanna, Piras, Pavan, & Vona, 2009; Krzykala *et al.*, 2016; Sparling *et al.*, 1998), with data from the modern international game giving a value of 15%, this lower value being linked to the shifting physiological demands of the game (Naicker, 2014). In younger players, Elferink-Gemser, Visscher, Lemmink, & Mulder (2007) compared the differences between female adolescent players (average age 13.9 ± 1.3 yr) selected and not selected to train in national age group teams, finding BF% of 18.8 ± 6.1% in selected players against 22.9 ± 7.1% in those playing at lower levels. A similar value of 17% is reported by Wassmer and Mookerjee (2002) in elite (tier 4) collegiate hockey players. International Russian (Fedotova, 2001) and Bulgarian (Georgieva, Kotsev, & Tomova, 2015) female adolescent hockey players have been recorded as having considerably lower BF% of between 10 and 14%.

In other intermittent team sports, football and rugby, body composition can vary considerably between individuals specialising in different playing positions (Bloomfield, Polman, Butterly, & O'donoghue, 2005; Harty *et al.*, 2019; Strauss, Sparks, & Pienaar, 2021). Macutkiewicz and Sunderland (2011) identified differences in the structure of play and playing demands for different positions in adult female hockey games and concluded that different physical strengths maybe appropriate for different positions. No difference in muscle mass or body composition was found between different playing positions in female US Collegiate players by Wassmer and Mookerjee (2002) but Calo*, et al.* (2009) studying body composition in female

Italian International players (28.8 ± 3.6 yr) found backs/goalkeepers had greater BF% and lower muscular mass than forward players and concluded that this reflected their “different training programs”. No studies have been done in female adolescent hockey players but a recent study in adolescent male players (16.2 ± 1.9 yr) also found no positional differences in body composition, concluding that the physiological characteristics amongst playing positions was not yet fully developed and that strength and conditioning programs are needed (Bandyopadhyay, Datta, & Dey, 2019).

There are numerous techniques that can be used to quantify fat mass and fat percentage, but all have inherent problems particularly when used in young athletes (Borga *et al.*, 2018) and there is no gold-standard body composition methodology in free-living individuals (Kasper *et al.*, 2021). Skin-fold measurement is the most frequently used method in field-based studies of athletic populations but the relationship between skin-fold thickness and body density changes considerably during puberty making this method more inaccurate during adolescence (Hergenroeder and Klish, 1990). In addition, the equations used to convert skin fold readings are based on adult norms (Hergenroeder and Klish, 1990) making the result of this conversion unreliable.

The prevalence of disordered eating in athletes competing in sports that emphasise leanness or low body fat is high (Sundgot Borgen and Torstveit, 2010), and adolescent athletes are often dissatisfied with their body image (Sundgot-Borgen and Torstveit, 2004), especially during puberty when they may gain a significant amount of fat (Martinsen, Bratland-Sanda, Eriksson, & Sundgot-Borgen, 2010). Sundgot-Borgen (1994) found that young athletes with eating disorders often felt that they had reached menarche too early and that a coach had told them to lose weight. As the risk of individuals identifying themselves as having a higher body fat than others or focusing on the implied benefits of low body weight is high the use of non-evasive predictive measurements may be preferable in younger athletes. Predictive equations are found to be highly population specific (Slaughter *et al.*, 1988; Thorland, Johnson, Tharp,

Housh, & Cisar, 1984) but the Jackson Equation (Jackson *et al.*, 2002), which uses BMI to give an estimate of BF% has been found to give an accurate measure of body composition in young populations (Mittal, Goyal, Dasude, Quazi, & Basak, 2011) and to have a lower potential risk of measurement error than using skin-folds (Nickerson *et al.*, 2018). The Jackson Equation is given as Equation 2.3.

Equation 2.3 Jacksons Equation to calculate body fat percentage

BF% = (1.39 x BMI) + (0.16 x age) – (10.34 x gender) – 9; where male = 1 and female = 0

2.2.2 Strength

In team sports, strength and power are important to exert the necessary forces involved in sprinting and changes in speed or direction (Komi, 1993). In hockey, the best players have been defined as those who can move most explosively (Anders and Myers, 2008), with frequent high intensity bursts of activity, acceleration, deceleration, direction change, tackling, striking, jumping, and diving all of which require explosive power output (Khanna, Majumdar, Malik, Vrinda, & Mandal, 1996; Reilly and Borrie, 1992).

2.2.2.1 Vertical and Countermovement Jump

Vertical jumping is a multi-joint movement that requires complex motor coordination and is identified as one of the fundamental movement skills (Gallahue, Goodway, & Jacqueline, 2011). The vertical jump test is a simple non-invasive method for calculating peak leg power using predictive equations based on jump height and body mass that can be compared with normative data for the general population and is an accepted functional measure of power in intermittent team sports (Keir, Jamnik, & Gledhill, 2003).

The assessment of vertical jump performance is regularly used to evaluate athletes sprint acceleration, deceleration and change of direction ability (Bui, Farinas, Fortin, Comtois, &

Leone, 2015; Comfort, Stewart, Bloom, & Clarkson, 2014; Helgerud, Engen, Wisloff, & Hoff, 2001; Manno, 2008; Meylan *et al.*, 2009; Spiteri *et al.*, 2014; Suchomel, Nimphius, & Stone, 2016) has also been used to gauge performance in male adolescent team sport (Rodríguez-Rosell, Mora-Custodio, Franco-Márquez, Yáñez-García, & González-Badillo, 2017). Normative data and percentile tables for children age 10-15 yr show that by age 11 yr, boys jump significantly higher than girls (Taylor, Cohen, Voss, & Sandercock, 2010) and continue to improve until 19 yr. Girls jump heights plateau after 12yr (Branta, Haubenstricker, & Seefeldt, 1984) but peak power continues to increase with maturity (Taylor*, et al.*, 2010). No research has recorded countermovement jump (CMJ) heights or leg power output in female adolescent hockey players but a review of football studies from 1995-2010 reported a mean jump height of under 18 girls as 27.9 ± 3.1 cm (Haugen, Tønnessen, & Seiler, 2012) and Datson (2016) documented the jump height in two studies of 15 yr old elite (tier 4) players as 26.6 ± 3.7 cm and 26.4 ± 3.4 cm. Although adult male hockey players have been found to perform better in most measures of jump performance, including countermovement jump height than male footballers the difference is small (Singh, Kumar, & Ranga, 2016) making the comparison with football studies interesting.

Although jump heights increase with age, the relationship may not be linear and jump performance during puberty may be influenced by changes in anatomical growth. In boys, jump height during the Mid-PHV phase has been found to be negatively affected by the emergence of growth spurt-related 'adolescent awkwardness' in some participants (Moran *et al.*, 2017). Physical performance could also be inhibited during the same period due to a decrease in relative strength associated with increasing body size (Moran, Sandercock, Ramirez-Campillo*, et al.*, 2017), a trend that can continue despite increases in absolute strength (Zatsiorsky and Kraemer, 2006). However, not all adolescent boys are found to experience disrupted sensorimotor abilities during growth and maturation (Quatman-Yates, Quatman, Meszaros, Paterno, & Hewett, 2012) and similar research has not been done in adolescent girls. It's possible the effect could be even more marked in girls due to

biomechanical changes in the lower limbs and greater joint laxity during adolescence (Quatman, Ford, Myer, Paterno, & Hewett, 2008; Sigward, Pollard, & Powers, 2012).

2.2.2.2 Hand Grip

Hand grip strength (HGS) is regularly associated with physical fitness and sports performance (Garrido *et al.*, 2012) regardless of age, gender or maturation (Matsudo, Matsudo, Rezende, & Raso, 2014). Adolescent boys have greater HGS than girls in all height, weight and age groups, with the differences widening after puberty (Wind, 2009). HGS in the general female adolescent population has been shown to increase not just by age but also by pubertal status (Matsudo*, et al.*, 2014). Female athletes have been found to be significantly stronger than their untrained female counterparts with HGS linearly correlated with lean body mass (Leyk *et al.*, 2007).

Hand grip is the most regularly used test for strength in hockey players and grip strength is important for handling the stick and executing skills (Bandyopadhyay*, et al.*, 2019). Elite (tier 4/5) and sub-elite (tier 2/3) female adult players have HGS of between 32 kg and 36 kg (Cochrane and Stannard, 2005; Keogh*, et al.*, 2003; Ucan, 2015; Wassmer and Mookerjee, 2002). There has been limited research on HGS in adolescent female hockey players but Fedotova (2001) studying 141 well trained Russian players aged 10 to 18 yr, demonstrated HGS of between 14 kg at age 10 yr and 44 kg at age 18 yr, as shown in table 2.1.

Table 2.1 Mean (±SD) hand grip strength (HGS) in Russian International adolescent hockey players. Adapted from Fedotova (2001).

	Age of Players (yr)								
Age	10 n=16	11 n=15	12 n=20	13 n=14	14 n=20	15 n=15	16 n=15	17 n=14	18 n=12
HGS (kg)	19.06 ± 5.09	22.53 ± 5.78	26.53 ± 6.50	29.73 ± 6.38	34.68 ± 6.06	35.85 ± 5.43	37.75 ± 2.60	39.57 ± 2.87	40.57 ± 3.64

Male adult hockey players have been found to have grip strengths of between 41 and 54 kg (Bandyopadhyay*, et al.*, 2019; Katsumura, 1986; Scott, 1991). These values are similar to male and female recreational tennis players (Vodak, Savin, Haskell, & Wood, 1980) and greater than those reported in football players (Manna, Khanna, & Chandra Dhara, 2010).

2.2.3 **Speed and Agility**

Over the past decade, the physical demands of hockey have evolved, reflecting the introduction of faster synthetic pitches, continuous substitution and rule changes that encourage high intensity matches with few breaks in play (FIH2021). These changes have resulted in lower total match distances but a greater proportion of high-speed running (HSR) and meters per minute ($m \cdot min^{-1}$) of play (Ihsan *et al.*, 2017; Mcmahon and Kennedy, 2019) making both speed and agility key factors in the modern game. HSR is an important discriminator between elite (tier 4/5) and sub-elite (tier 2/3) team sport adult athletes (Mohr, Krustrup, & Bangsbo, 2003). Repeated back-to-back sprints make speed an important characteristic in hockey players (Reilly and Borrie, 1992) and the requirement to accelerate and sprint at maximal or near maximal intensity are also important. Macleod, Bussell, & Sunderland (2007) reported female internationals completed 960 ± 272 motion changes during games equating to an activity change every 3 s. Time motion analysis (TMA) in men's hockey games indicate that hockey players perform on average 30 sprints per game, with mean sprint duration of approximately 2 seconds (Spencer, Bishop, & Lawrence, 2004). This analysis has not been repeated in the female game but Keogh *et al* (2003) recorded that female players ran 10 m and 40 m sprint in a time of 2.01 ± 0.02 s and 6.53 ± 0.09 s respectively, confirming the games fast pace.

Sprint speed over a given distance improves progressively during childhood. Running speed during a sprint is a product of stride length multiplied by the number of strides taken and so

would be expected to be directly related to height (Romann and Fuchslocher, 2013; Schorer, *et al.*, 2009; Vincent and Glamser, 2006) but is not the only parameter that influences speed and physical maturation, and changes in muscle development are found to have a greater impact on match running performance (Buchheit and Mendez-Villanueva, 2014).

In hockey, it is important for players to be quick and agile, both while in contact and not in contact with the ball. Lothian *et al* (1994) demonstrated that female hockey players are in contact with the ball or dribbling for between 18 and 30% of match-time. Consequently, a lot of emphasis is put on an individuals' movement on the ball and highly trained (tier 3/4/5) hockey players need a high-level of technical skill to dribble without losing running speed. Better players in hockey are found to have superior running speeds while dribbling the ball (Reilly and Bretherton, 1986) and similar results have been found in football (Reilly, Williams, Nevill, & Franks, 2000).

Due the importance of these skills and the unique requirements of hockey's quick movement, changes in direction and the semi-crouched posture, Lemmink, Elferink-Gemser and Visscher (2004) developed the 'hockey specific shuttle sprint and dribble test' (ShuttleSDT) and 'slalom sprint and dribble test' (SlalomSDT). These tests were designed to measure both physiological and technical ability and were based on tests for repeated sprint ability, (Aziz, Chia, & Teh, 2000) agility, (Pauole, Madole, Garhammer, Lacourse, & Rozenek, 2000) and dribbling skills in both hockey (Reilly and Bretherton, 1986) and football (Reilly and Holmes, 1983; Van Rossum and Wijbenga, 1993). Both tests have been found to be reliable methods of assessing skill, agility and speed (95% confidence intervals for mean differences between test days) (Lemmink, Elferink-Gemser, & Visscher, 2004) but the course, duration, and repetitive nature of the ShuttleSDT is considered of more significant for defenders and midfielders, whereas the course of the SlalomSDT makes the test potentially more relevant to forwards (Lemmink, *et al.*, 2004). Both tests were designed and tested on a homogeneous group of 'talented' youth hockey players, and age or gender differences were not thought to be significant (Lemmink,

et al., 2004). Elite female youth hockey players (tier 4) are shown to score better than the sub-elite players (tier 3) on both tests for dribble performance component but not in the sprint component alone (Elferink-Gemser*, et al.*, 2004).

There are no published studies which have documented the influence of maturity on speed or agility in female adolescent hockey players. Research within male football players has shown that both speed and agility are positively influenced by biological maturity (Figueiredo, Gonçalves, Coelho E Silva, & Malina, 2009; Mirkov, Kukolj, Ugarkovic, Koprivica, & Jaric, 2010; Philippaerts*, et al.*, 2006) but that there is some evidence of decline in motor coordination and physical performance during puberty (Philippaerts*, et al.*, 2006) this has not yet been demonstrated during female adolescence.

2.2.4 Aerobic Power and Endurance Capacity

Match analysis of hockey consistently shows that it is a high intensity non-continuous game in which the physiological demands are considerable (Reilly and Borrie, 1992). Bishop and Girard (2011) found that optimum physical performance in most sports results from a combination of sprint performance and the ability to recover between efforts. In hockey, performance is related to the ability to perform the high intensity elements, running and sprinting involving anaerobic capacity and to recover well during low intensity elements, standing, walking or jogging and so is related to both aerobic and anaerobic capacity (Keogh*, et al.*, 2003).

In non-athletes, anaerobic capacity has been shown to increase with age (Martin and Malina, 1998) and aerobic capacity to increase proportionately to increases in body size and mass (Krahenbuhl, Skinner, & Kohrt, 1985). In girls, increases plateau at ~15 yr but in boys are seen to increase until around 19 yr (Elferink-Gemser, Visscher, Van Duijn, & Lemmink, 2006). However, using multilevel modelling to predict development of interval endurance capacity in

talented youth hockey players, Elferink-Gemser *et al* (2006) demonstrated that unlike non-athletes talented female hockey players continued to see improvement in interval endurance capacity following a track of improvement more similar to boys. This was also linked to lower BF%, greater training hours and increased motivation in athletes compared to non-athletes (Elferink-Gemser*, et al.*, 2006).

Maximal Oxygen uptake has been identified as a key factor in determining team sport performance (Stone and Kilding, 2009). The multistage fitness test (MSFT) was originally developed for use in adults by Leger and Lambert (1982) and adapted by Ramsbottom, Brewer, & Williams (1988) and Wilkinson, Fallowfield, & Myers (1999). The test demonstrates strong test-retest reliability and validity (Tomkinson and Olds, 2008) and a systematic review concluded that 20-m shuttle run tests are the most reliable and valid field-based method that can be used to estimate aerobic fitness in young people (Castro-Piñero *et al.*, 2010). Performance is typically expressed as laps, levels or distance completed but can also be used to calculate a measure of peak VO_2 using equations counting for age, sex, and size of the participant (Mahar, Guerieri, Hanna, & Kemble, 2011; Wilkinson*, et al.*, 1999). However, caution must be taken, and the error associated with the estimation of peak VO_2 (typically 4 – 6 $mL \cdot kg^{-1} \cdot min^{-1}$) should be considered when interpreting data. It should also be noted that endurance run tests requires participants to self-pace their performance and can lead to recording a sub-maximal exertion and an underestimation of peak VO_2, particularly in younger participants (Cureton, Sloniger, Black, Mccormack, & Rowe, 1997). VO_{2max} tests can show improvement with age due to improved running economy and better pacing ability, rather than an increase in aerobic capacity (Cureton*, et al.*, 1997). The 20 m shuttle run test is thought to minimise this risk by being easy to conduct and due to its familiarity and regular use within adolescent athletic populations (Liu, Plowman, & Looney, 1992).

Peak VO_2 rises during pre-pubertal years in a curvilinear fashion in both boys and girls and although there is considerable overlap in the data, average male adolescent VO_{2max} is

consistently higher. Armstrong and Welsman (1994) showed peak VO_2 12% higher in boys than girls at 10 yr, increasing to 23% at age 12 yr and 37% by age 16 yr. Increases in peak VO_2 with age, in children and adolescents is thought to largely reflect the increased dimensions of oxygen delivery system and increased mass of exercising muscle (Rowland, 1989). Peak VO_2 and body mass are strongly correlated (Armstrong, 2000). Strong normative data exists for adolescents within the general population for English school children (Sandercock, Voss, Cohen, Taylor, & Stasinopoulos, 2012), European children and adolescents (Moran, Sandercock, Ramirez-Campillo*, et al.*, 2017) and Internationally (Tomkinson *et al.*, 2017). The American College of Sports Medicine (ACSM) (Liguori, 2021) provide suggested categories of VO_{2max} performance for each gender and age group as shown in Table 2.2.

Table 2.2 Normative Data for VO2max in adolescent girls and adult females. Adapted from Liguori (2021) ACSM Guidelines for Exercise Testing and Prescription 11th Edition.

AGE (yr)	Assessment of Fitness Level					
	VERY POOR	POOR	FAIR	GOOD	EXCELLENT	SUPERIOR
13-19	<25.0	25.0-30.9	31.0-34.9	35.0-38.9	39.0-41.9	>41.9
20-29	<23.6	23.6-28.9	29.0-32.9	33.0-36.9	37.0-41.0	>41.0
30-39	<22.8	22.8-26.9	27.0-31.4	31.5-35.6	35.7-40.0	>40.0

In the only data published for female adolescent hockey players Pal, Dey, Neha, Medbala, & Adhikari (2017) reported Indian players attending a performance academy (age 15.9 ± 2.2) as having peak VO_2 values of 40.6 ± 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$, assessed as excellent against the ACSMs matrix. Very high, superior VO_{2max} levels have been found in female adolescent netball players (14.1 ± 0.8 yr, 44.5 ± 3.6 $mL \cdot kg^{-1} \cdot min^{-1}$) (Rumbold, 2011) and in adolescent female runners

(16.0 ± 0.8 yr, 48.0 - 63.2 mL·kg-$^{-1}$·min^{-1}) (Fernhall, Kohrt, Burkett, & Walters, 1996) both calculated from MSFT.

Adult hockey players have been reported to have a range of VO_{2max} values ranging between 43.9-59.03 mL·kg^{-1}·min^{-1} in treadmill tests and 42.87 ± 9.08 mL·kg^{-1}·min^{-1} from bench stepping (Astorino, Tam, Rietschel, Johnson, & Freedman, 2004). Direct measures of VO_{2max} in female football players have been measured ranging from 49.4-57.0 mL·kg^{-1}·min^{-1} (Andersson, Karlsen, Blomhoff, Raastad, & Kadi, 2010; Haugen, Tønnessen, Hem, Leirstein, & Seiler, 2014; Ingebrigtsen, Dillern, & Shalfawi, 2011; Mohr, Ellingsgaard, Andersson, Bangsbo, & Krustrup, 2003), with elite players (tier 4/5) recording higher values than university or lower league players (tier 2/3) (Krustrup, 2005). Reported VO_{2max} calculated using MSFT scores have been found to be lower in elite players (tier 4/5); ranging from 43.2-50.3 mL·kg^{-1}·min^{-1} (Manson, Brughelli, & Harris, 2014; Tumilty, 2000; Tumilty and Darby, 1992) and the ability to calculate VO_{2max} using MSFTs has been questioned in young female football players (Castagna, Impellizzeri, Manzi, & Ditroilo, 2010).

2.3 Activity patterns & physiological demands in adolescent hockey.

2.3.1 Time Motion Analysis (TMA) and Global Positioning System (GPS) Analysis

To assess the physiological impact and nutritional requirements of training and match-play in children and adolescents, it is important to understand the underlying demands and structure of play involved in playing team sports at this age. Team games are all intermittent, with prolonged periods of moderate to low intensity activity randomly interspersed with brief periods of high and maximal intensity work (Bishop and Claudius, 2005). However, the characteristics of each game are highly variable, and demands can vary between playing position as well as

the age and gender of players, level of the game, type of opposition and climatic conditions (Ihsan*, et al.*, 2017; Macutkiewicz and Sunderland, 2011; White and Macfarlane, 2015a). The flow of each game will also vary considerably making accurate quantification of game demands difficult (Mujika and Burke, 2010).

The use of GPS provides a quick and accurate method to describe and analyse the physiological demands of sport (Aughey, 2011; Cummins, Orr, O'connor, & West, 2013; Edgecomb and Norton, 2006; Macleod, Morris, Nevill, & Sunderland, 2009; Townshend, Worringham, & Stewart, 2008). Most of the early work on the demands of hockey was done using manual video-based TMA, which was time consuming (Roberts, Trewartha, & Stokes, 2006) and often inherently inaccurate (Bradley *et al.*, 2009; Lames and Mcgarry, 2007). Constantly evolving rule changes in hockey over the last decade have also made early research less relevant to the modern game (Holmes, 2011). Table 2.3 summarises all the female and adolescent hockey research from 2010 to the present-day using video analysis and GPS technology for motion analysis.

Table 2.3 Current research using GPS analysis in female adolescent hockey players. F= Forwards or Strikers, M = Midfield Players. S = Screen Players and B = Defenders or Backs

Research	Level & Age	Method used	Distance (m)	Average time on pitch (mins)	m·min^{-1}	Max velocity (km·h^{-1})	Low (% of time)	Moderate (% of time)	High (% of time)
Gabbett (2010)	Elite adult (tier 3/4/5) Age 23.3 ± 3.2	GPS	6,600 (3,400-9,500) F = 6,154 ± 271 M = 6,931 ± 1882 B = 6,643 ± 1618				97% of play low to moderate intensity		Midfielders spent more time and covered greater distances in high intensity running (>5 m·sec^{-1})
Macutkiewicz and Sunderland (2011)	Elite adult (tier 4/5) Age 26.2 ± 3.5	GPS	5541 ± 1144	48 ± 4 F = 38 ± 7 M = 50 ± 10 B = 56 ± 11	Reported in McGuinness *et al* 2017 as 115.4 ± 23		55.5 ± 6.3 Stand 5.8 ± 2.7%, Walk 49.7 ± 5.6%	38.1 ± 5%. Jog 25.8 ± 3.5% Run 12.3 ±0.9%	Fast run 4.9 ± 1.4% Sprint 1.5 ± 0.6%
Holmes (2011)	Elite (tier 4/5) Mixed international teams	TMA/video	9,100 ± 1,600 F = 9,750 ± 1,700 M = 9,560 ± 1,400 B = 7,840 ± 720				F-70.4±9.1 M-71.7±7.8 B-82.1±4.5		F-29.6±9.1 M-28.3±7.8 B-17.8±4.5 10.3±6.0 sprint
Leslie (2012) Ch 6	Elite adult, U16 and U18 (tier 4) Age 24.5 ± 0.8, 16.2 ± 0.1 & 17.6 ± 0.2	GPS	U16 = 4962 ± 295 U18 = 5203 ± 156 Adult = 5581 ± 209	U16 = 46 U18 = 46 Senior = 49	108 ± 6 113 ± 3 114 ± 4	U16 = 23.3 ± 0.6 U18 = 23.5 ± 115.5 Adult 24.3 ± 0.3	U16 = 58.7 ± 2.5 U18 = 36.2 ± 1.7 74.1 ± 3.9 Adult 54.0 ± 1.8	U16 36.2 ± 1.7 U18 37.9 ± .2 Adult 38.5 ± 1.4	U16 5.0 ± 0.8 U18 5.9 ± 0.6 Adult 7.5 ± 0.6
Leslie (2012) Ch 7	Sub elite adults (tier 2/3) Age 20.8 ± 0.5	GPS	7230 ± 147	69 ± 26	104.7 ± 2	Max speed 23.0 ± 0.3	66.2 ± 1.3	29.7 ± 1.1	4.1 ± 0.3

Leslie (2012) Ch 8	Sub elite adult. University 1sts, 2nds & 3rds (tier 1/2/3/4) Age 1sts - 21.4 ± 1.0 2nds – 20.1 ± 0.4 3rds – 20.4 ± 0.2	GPS	1st – 7346 ± 242 2nd – 7124 ± 236 3rd – 7171 ± 247	1st - 74.10 ± 0.82 2nd - 73.23 ± 0.72 3rd - 3.53 ± 0.67	1st - 99.3 2nd - 97,6 3rd - 98.2	1st – 22.7 ± 0.6 2nd - 22.5 ± 0.2 3rd - 23.4 ± 0.5	1st – 66 ± 1 2nd – 66 ± 2 3rd – 66 ± 3	1st – 30 ± 1 2nd – 30 ± 2 3rd – 30 ± 2	1st – 66 ± 3 2nd – 30 ± 2 3rd – 4 ± 0	
Boran (2012)	Sub elite adults (tier 1/2) Age 28 ± 8.4	GPS	F= 6009 ± 796 M= 6660 ± 542 B= 5896 ± 801							
Vescovi (2014)	Sub elite adults (tier 3/4) College U17 & U21	GPS				U17- 24.6 ±1 .8 U21- 25.0 ± 1.0 F- 25.5 ± 1.8 M- 24.7 ± 1.3 B- 24.3 ± 1.1				
White and Macfarlane (2015b)	Sub elite adults (tier 3/4) Age = 16-39 yr	GPS	mid vs top ranked - 6498 (5583-7413) mid vs low ranked - 5949 (4726-7171) Closely ranked - 7719 (7194-8224)		Close ranked opposition 103 (93-113) m·min^{-1}					
Vescovi and Frayne (2015)	Sub elite adults (tier 3/4)	GPS	F=6062 ± 1371 (5438-6686) M=6765 ± 392 (6235-7294) B=6556 ± 1120 (5999-7113)	F=56.5 ±13.1 (51-62) M= 62.9 ± 13.4 (58-68) B= 68.2 ±12.0 (62-74)	F = 110 ± 11(104-115) M= 109 ±11 (105-113) B= 98 ± 11(92-103) U21 Canadian team = 112	F = 25.0 ± 1.4 (24.3-25.6) M = 24.4 ± 1.4 (23.8-24.9) B = 23.8 ± 2.0 (22.8-24.8)	Distance not time F = 39% M = 39% B = 45%	F = 47% M = 48% B= 45%	F = 11% M = 10% B = 1%	
Vescovi (2016)	Sub elite adults College (tier 3/4)	GPS	U17 – 4071 ± 1476 (3448-4696)	U17 – 39 ± 15.8 (32-46) U21 - 42 ± 8.7 (38-46)	U17 – 107 ± 9 (103-111) U 21 = 112 ± 6 (110-115) F – 111 ± 6 (108-114) M – 113 ± 6 (110-116)	Max velocity in games =24km·h^{-1} Max velocity in lab tests	Distance not time. U17 – 42 U21 – 38		U17 – 9	

	U17 & U21		U21 – 4,688 ± 928 (4254-4695) F – 3,283 ± 842 (2817 – 3750) M – 4735 ± 1305 (4064 – 5406) B – 5,143 ± 759 (4661 – 5626)	F – 29 ± 7.8 (26-34) M – 42.1 ± 11.8 (36-48) B – 51 ± 10.3 (44-58)	B – 103 ± 9 (97 – 109)	U17 – 27.9 ± 1.3 U21 – 27.3 ± 1.5, F – 27.9 ± 1.4 M – 27.4 ± 1.6 B – 27.6 ± 1.4	F – 38 M – 38 B – 46	U17 – 46 U21 – 48 F - 47 M – 49 B – 44	U21 – 11 F – 12 M – 10 B – 8
Abbott (2016) Study 1	Elite adult. US National Team (tier 4/5) Age - 25.5 ± 0.17	GPS	F = 3091 ± 1094 M = 3264 ± 985 S = 2293 ± 701 B = 5912 ± 1378	F = 38.3 ± 1.3 M = 41.4 ± 8.3 S = 57.0 ± 3.0 B = 57.5 ± 11.4	F -117 ± 11 M – 120 ± 11 S – 118 ± 11 D – 114 ± 9		.		
McMahon and Kennedy (2017)	Elite adult. Irish National Team. (tier 4/5) Age = 23.4 ± 4	GPS	Game as halves F= 4313 ± 784 M = 5195 ± 747 B= 5182 ± 1052 Game as quarters F = 4789 ± 968 M = 5431 ± 961 B = 5228 ± 1088	Game as halves F=38.6 ± 5.3 M= 46.6 ± 7.3 B = 51.9 ± 11.9 Game as quarters F=40.1 ± 8.5 M= 45.7 ± 10.1 B= 49.1 ± 13.5		Game as halves F=24.2 ± 1.5 M=24.0 ± 2.5 B=23.3 ± 1.2 Game as quarters F= 24.7 ± 1.6 M= 24.2 ± 1.4 B= 23.4 ± 1.3			
Mcguinness, Malone, Hughes, & Collins (2017) & Mcguinness *et al.* (2018)	Elite adult (tier 4/5) Age = 24 ± 5		5558 ± 527 F= 5369 ± 578 (4300-6185)	44± 7 F= 41 ± 6 (34-51)	125 ± 23 F=131 ± 10 116-146				

			M= 5555 ± 456 (4939-6160) B= 5696 ± 530 (4942-6574)	M=43 ± 5 (37-49) B=50 ± 8, (40-60)	M=129 ± 5 (121-138) B=114 ± 7 (103-123)				
Kusnanik, Rahayu, & Rattray (2018)	Sub-elite adult (tier 3) Age = 20.3 ± 2.2 (19-21)	Video	4372 ± 264 (3432-3669)						
Mcguinness, Malone, Hughes, Collins, & Passmore (2019)	Elite adult (tier 4/5) Age - 23 ± 3	GPS	4847 ± 583 F=4549 ± 546 M=4740 ± 530 B=5181 ± 607	38 ± 8 F= 32 ± 7 M=36 ± 6 B=45 ± 8	127.6 ± 15.6	24.3 ± 1 F=24 ± 1 M=24 ± 1 B=25 ± 1	54	44	12
Vinson, Gerrett, & James (2018)	Sub elite adult (tier 3/4) Premier League Age = 28.0 ± 7.0 (all over 18)	GPS		F = 57.5 M= 62.6 B = 68.8	M = 117.2 ± 4.4 B = 99.8 ± 4.4				
Delves, Bahnisch, Ball, & Duthie (2019)	Sub-elite adult (tier 3) Age – 22 ± 2 (19-25)		F = 5364 ± 894 M = 5266 ± 1074 B = 5301 ± 1120	F = 51 ± 8 M = 47 ± 10 B = 55 ± 10	F = 105 M = 112 B = 96.4				
Mcguinness, Passmore, Malone, & Collins (2020)	Elite adults Irish National Team (tier 4/5) Age – 23 ± 3				F = 119.3 ± 19.0 M = 106.8 ± 23.4 B = 100.7 ± 19.7				

2.3.2 International Hockey Federation Rule Changes

The International Hockey Federation (FIH) is responsible for the rules of hockey. The rules are reviewed on a constant basis and updated every two years, the last review being in 2021 (FIH 2021). Before 1970, all hockey was played on grass, the first International Tournament on AstroTurf being played in 1975. The move to AstroTurf significantly changed the character of the game, making it much faster and allowing the ball to be dribbled at speed, something that had not been possible on grass. Malhotra and Khanna (1983) showed that the physical demand of playing hockey on AstroTurf was substantially greater (+18%) than playing on grass, despite there being little difference in the skills used (Sharma and Dasnd, 2017). Other major changes have been the introduction of unlimited substitutes and the abandoning of the off-side rule. No substitutions were permitted in games before 1973. Initially, the ability to play two permanent substitutes was permitted, then three and then in 1995 rolling substitution was introduced (Jennings, Cormack, Coutts, & Aughey, 2012b). Unlimited rolling substitutions with a squad of 16 players moved the game up in intensity; with players being found to cover the same distance with more high intensity passages of play despite spending time off the pitch (Jennings*, et al.*, 2012b; Mcmahon and Kennedy, 2019; White and Macfarlane, 2013). The loss of the off-side rule (1992) also made the game faster and has led to an increase in the amount of time the ball is played in the air, particularly at international level. In May 2009, the FIH introduced the 'self-pass' rule, allowing players to restart play from a free hit by passing the ball to themselves enabling the game to flow more freely. Since 2014 some International Games have been played in four quarters shifting the emphasis from endurance to speed and agility, and this rule change was adopted for all National League games in 2018. Abbott (2016) and McGuinness *et al* (2017) researched the impact of these changes and concluded that the change to quarters and the introduction of stopped time for penalties and injuries have both significantly positively impacted the speed and intensity of the game. Due to these

changes in rules, the research on the movement within hockey games or the physiology of player's from before 2014 may not be comparable to the modern game (Abbott, 2016; Mcguinness, Malone, Hughes*, et al.*, 2017; Mcguinness*, et al.*, 2020; Sharma and Dasnd, 2017).

2.3.3 Distance Covered

Most studies that use TMA report the distance covered by players as a marker of a player's physical activity. The average total distance covered by adult female players during a game ranges from 2,300 m for screen players (tier 4/5) (Abbott, 2016) to 7,719 m (7,194-8,224 m) across all positions in games between closely ranked teams (tier 3/4) (White and Macfarlane, 2015b). However, no indication of the proportion of the 70 minute game each individual player spent on the pitch was provided by White and Macfarlane (2015b) and although the average pitch-time was provided by Abbott (2016) as 41 minutes, players with the lowest recorded distances (screen players) averaged a pitch time of just 19 minutes, less than a third of playing time. In comparison to International games (tier 4/5), studies in female US College Players (tier 3/4) (Vescovi and Frayne, 2015) and UK University Teams (tier 1/2/3/4) (Leslie, Morris, Sunderland, & Nevill, 2008) show high distances travelled (6,062 ± 1,371 and 7,230 ± 147 m respectively) but also higher times on the pitch (74 ± 3 and 57 ± 13 minutes).

The only study to document distance covered in adolescent female hockey players, (Leslie, 2012) found U16 players (tier 4) covered 4,962 ± 295 m and U18 (tier 4) 5,203 ± 156 m with an average playing time of 46 minutes. In adult male players, the distance travelled has been found to be unrelated to the time spent on the pitch (White and Macfarlane, 2013), this has not been investigated in female or adolescent players. For female hockey players, relative distance or total distance travelled per minute of competition game time ($m \cdot min^{-1}$) may provide a more accurate reflection of match

intensity than total distance covered, taking event time into account as well as an individual player's time on the pitch. Relative distance in $m \cdot min^{-1}$ is now a commonly used measure in team sport analysis where player substitution gives uneven playing times and it is also valuable when comparing junior and senior games (Beenham *et al.*, 2017; Cunningham *et al.*, 2016; Henderson, Cook, Kidgell, & Gastin, 2015; Torres-Unda *et al.*, 2016). This is particularly important in adolescent hockey where rolling substitution of squads with 16 players means the amount of time played can vary considerably between individual players, different positions, or different game formats. Match lengths often vary between club, school, national and international competitions. The effect of these differences has been studied in football and rugby but not hockey (Atan, Foskett, & Ali, 2014; Cunningham*, et al.*, 2016).

Analysis of the relative distance covered also allows better study of positional differences in the demands of team play. Adult defensive and midfield players frequently cover greater distances overall but lower distances per minute of pitch time (Abbott, 2016; Delves*, et al.*, 2019; Mcguinness*, et al.*, 2019; Mcguinness*, et al.*, 2020; Vescovi, 2016; Vescovi and Frayne, 2015; Vinson*, et al.*, 2018). It is unclear as to whether this relationship holds in young players where positional zones of play may not be as well defined. There has been speculation that child and adolescent team sport players cover greater distances than adults due to higher work rates (Bar-Or, 1977), lower tactical awareness and poor ball control (Payne and Isaacs, 2011; Williams, 1983). However, this has not been found in male academy football players; age being positively associated with total distance covered and distance travelled per minute. U18 players cover 27% greater distance than U13 players (Buchheit, Mendez-Villanueva, Simpson, & Bourdon, 2010) and U16 players covering a 10% higher relative distance than U13 players (115.2 $m \cdot min^{-1}$ vs 103.7 $m \cdot min^{-1}$) (Harley *et al.*, 2010). Van Der Merwe and Platt (2019) comparing the comparative demands of U18, U21 and senior male hockey players (tier 3) found that the running demands are age and position specific but that

there was no clear trend with increasing age. This has not been studied in younger male or female hockey players. Wylde (2014) recorded U17 male hockey players (tier 4/5) covered a relative distance of 104.5 – 113.1 $m \cdot min^{-1}$ in line with the relative distance covered in adult games. Cunningham (2016) examined match differences and substitution in youth rugby and suggested that understanding the changes in relative distance travelled and match intensity as individuals progress from youth into adult leagues is an important variable when examining whether players are being prepared adequately for senior competition.

2.3.4 **Game Intensity and Velocity Bands**

To examine the intensity of games, studies have broken down movement into velocity bands by grouping the time spent walking, jogging, running, and sprinting into low, moderate, and high intensity bands. Before any rule changes, Lothian and Farrell (1994) reported that elite (tier 4) female players spent 78% of match time involved in low to moderate intensity activities such as standing, walking and jogging and 22% doing high intensity activity. More recently female club players (tier 2/3) have been shown to spend as much as 97% of match time in low intensity activity (Boddington, Lambert, Clair, & Noakes, 2002; Gabbett, 2010) and international female players (tier 4/5) 92-94% (Gabbett, 2010; Macleod*, et al.*, 2007; Macutkiewicz and Sunderland, 2011). These findings are in line with male hockey games where 85- 89% of pitch time has been identified as low intensity (Johnston, Sproule, Mcmorris, & Maile, 2004; Paun, 2008). It is hard to compare studies as the time spent in different velocity bands will depend on the banding used to classify a sprint, run, jog or walk and can be difficult to interpret (Sweeting, Cormack, Morgan, & Aughey, 2017).

Most studies have used set descriptors of the different speed bands but (Vescovi, 2016) in the analysis of U17 and U21 female hockey players performance used individualised

speed bands. The relative merits of using individual velocity bands or generalised bands are discussed by Sweeting*, et al.* (2017) with the conclusion that practitioners should select thresholds of an equal bandwidth and that sports should try to standardise bands used to allow better comparison. A wide variety of velocity bands have been used for the analysis of female hockey games, with little consensus on the number of categories or band velocity (Abbott, 2016; Gabbett, 2010; Macutkiewicz and Sunderland, 2011; Vescovi, 2016; Vescovi and Frayne, 2015). The most common banding used within hockey and football research (Abbott, 2016; Clarke, Anson, & Pyne, 2015; Datson *et al.*, 2017; Dwyer and Gabbett, 2012; Holmes, 2011; Macutkiewicz and Sunderland, 2011; Mcmahon and Kennedy, 2019) is shown in Table 2.4.

Table 2.4 Velocity bands originally defined by Bangsbo, Nørregaard, & Thorsoe (1991) and Lothian, F. and Farrally (1992) for the use in male and female adult football and hockey games.

Speed	Description	Speed Bands
0 – 0.6 km·h^{-1}	Standing	LOW
0.7 – 6.0 km·h^{-1}	Walking	
6.1 – 11.0 km·h^{-1}	Jogging	MODERATE
11.1 – 15.0 km·h^{-1}	Running	
15.1 – 19.0 km·h^{-1}	Fast Running	HIGH
> 19.0 km·h^{-1}	Sprinting	

Due to expected lower running speeds in young and female athletes, Leslie (2012) proposed different bands for use with junior and female hockey players and these have been adopted in recent male U18 studies (Van Der Merwe and Haggie, 2019; Wylde, 2014). The low intensity bands were comparable to previous studies but the sprint velocities were lowered to reflect the inclusion of young players (Bradley and Vescovi, 2015; Leslie, 2012) as shown in Table 2.5. Equivalent lower velocity bands are commonly used in elite (tier 3/4/5) female football; high-speed running being classified as >14.4 km·h^{-1} and sprinting >19.8 km·h^{-1} (Bradley *et al.*, 2011; Datson*, et al.*, 2017).

Table 2.5 Speed bands adapted for use in young and female hockey players by Leslie (2012) with lower high intensity bands.

Speed	Description	Speed Bands
0 – 3.0 km·h^{-1}	Standing	LOW
3.1 – 6.0 km·h^{-1}	Walking	
6.1 – 10.0 km·h^{-1}	Jogging	MODERATE
10.1 - 14.5 km·h^{-1}	Running	
14.6 – 19.0 km·h^{-1}	Fast Running	HIGH
> 19.0 km·h^{-1}	Sprinting	

The amount of playing time involved in both low/moderate activity and high intensity movement in elite male football is similar to that seen in hockey. At club and international level ~91-95% of time is spent in low/moderate intensity activity, with 5-9% of time as high intensity bouts (Bloomfield, Polman, & O'donoghue, 2007; Bradley*, et al.*, 2009; Mohr, Krustrup*, et al.*, 2003). Very few studies have been conducted with elite female football players but Krustrup (2005) showed players (tier 3/4) spend 95.2% of time in low/moderate and 4.8% high intensity activity and Datson*, et al.* (2017) found that in elite (tier 4/5) UK female international football games walking and jogging accounted for ~85% of total distance and HSR 24% of total distance. These studies are difficult to compare looking at time vs distance and it should also be noted that over the time between studies women's football was changing and becoming increasingly professional. Recent studies in football have shown that running intensity fluctuates and that in the minutes following a high intensity effort there is a temporary performance decrement (Fransson, Krustrup, & Mohr, 2017). International male and female hockey players (tier 4/5) complete more HSR in all positions than players in elite national or amateur teams (tier 1/2/3/4) (Gabbett, 2010; Jennings, Cormack, Coutts, & Aughey, 2012a; Jennings*, et al.*, 2012b). This has also been found in female football, where the amount of HSR and sprinting by female players is higher at higher standards of competition (Datson*, et al.*, 2017), female players competing in international football matches performing 28% more HSR and 24% more sprinting than those competing in domestic matches (Krustrup, 2005). Female football

players also produce more repeated-sprint bouts during international matches compared to national league (Gabbett and Mulvey, 2008) and the same players will do more HSR (13%) and sprinting (14%) when playing an international game compared to a domestic game (Andersson *et al.*, 2008).

There has been little research on the impact of different starting formations or defensive tactics on distance travelled or motion changes. Konarski and Matuszynski (2006) studied the impact of different defensive tactics on heart rate responses and estimated energy expenditure (EE) in male hockey players and found that when zonal marking, players had lower average heart rates (HR) than when marking man-to-man suggesting that the movement during games may be heavily influenced by the different tactics used. In football, no difference is found in distance covered when using different starting formations (Bradley*, et al.*, 2011) but more defensive systems were found to reduce the amount of high intensity running. To date, there has been no published work on movement during adolescent hockey games, or positional differences in match intensity.

2.3.5 Heart Rate (HR)

HR is easily measurable in adolescent populations and can be used to assess exercise intensity, exertion and recovery (Liguori, 2021). Maximum heart rate (HR_{max}) can be measured using a progressive maximal exertion protocol such as the MSFT or calculated using predictive equations (Machado and Denadai, 2011; Tanaka, Monahan, & Seals, 2001). Table 2.6 shows a summary of physical activity intensity categories for children and adolescents aged 8-18 yr based on HR, maximum oxygen uptake, perceived exertion, and metabolic equivalent (MET with 1 MET equal to 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ oxygen consumed). HR_{max} in children and adolescents can be calculated using Equation 2.4, which is found to be more accurate when used in children and adolescents than the often cited $HR_{max} = 220 – age$ (Machado and Denadai, 2011).

Equation 2.4 Equation to calculate estimated HR_{max} in children & adolescents

$HR_{max} = 208 – (0.7 * age)$

2.4 Energy Requirements in Adolescent Athletes

2.4.1 Total Energy Expenditure (TEE)

The accurate calculation of energy needs is crucial when providing evidence-based guidance to adolescent athletes. As well as being important for performance, the provision of food intake supported by accurate estimation of individual energy needs can be used to inform strategies for improved immunity (Walsh *et al.*, 2011), reduced susceptibility to injury (Ihle and Loucks, 2004; Thein-Nissenbaum, Rauh, Carr, Loud, & Mcguine, 2011), beneficial endocrine changes (Degoutte *et al.*, 2006) and lower menstrual disturbance (Reed, De Souza, & Williams, 2013). Sufficient energy intake (EI) is crucial for training consistency and performance particularly during periods of intense training or competition (De Souza *et al.*, 2014; Logue *et al.*, 2018; Logue *et al.*, 2020; Mountjoy, 2018). Prolonged energy restriction can lead to impaired physiological function, increased risk of fatigue, illness or injury and poor adaptation to training (Bergeron*, et al.*, 2015; Mountjoy, 2018; Mountjoy *et al.*, 2014). Energy homeostasis and consistency of intake are also linked to appetite and subsequent energy intake, under-fuelling leading to the potential of poor dietary intake (Blundell, Finlayson, Gibbons, Caudwell, & Hopkins, 2015; Keesey and Powley, 2008).

Table 2.6 Categories of Physical Activity for children and adolescents aged 8-18 yr. Adapted from Raghuveer et al. (2020), where MET = Metabolic Equivalent adjusted for use in children and adolescents, HRmax = Maximal heart rate, HHR = Heart rate reserve (HRmax – resting HR), RPE = Borg's Rating of perceived exertion (range 6-20) and VO_{2max} = Maximal oxygen uptake. MET levels for light activity were adjusted to 1.5 - 3 MET and for moderate to 3.1 - 6 MET in line with the majority of studies in children and adolescents (Lynch *et al.*, 2019).

INTENSITY	DESCRIPTION	EXAMPLES	MEASURES (Mean values for 8-18 y of age)
SEDENTARY	Waking behaviour typically performed in a sitting or reclining posture.	Watching television, watching films, sitting in a car, reading, fishing, working, or studying at a desk or in a classroom.	< 1.5 METs < 40% HR_{max} < 20% HHR < 20% VO_{2max} RPE < 8
LIGHT	Light aerobic activity that does not cause a noticeable increase in breathing and can be sustained for at least 60 minutes	Domestic or occupational tasks such as washing dishes, ironing, video games, driving a car, jobs involving standing and walking short distances, actively working at a desk.	1.5 - 3 METs 40 - 63% HR_{max} 20 - 39% HHR 20 - 45% VO_{2max} RPE 8 - 11
MODERATE	Aerobic activity that can be sustained whilst maintaining a conversation uninterrupted.	Gentle swimming, social tennis, golf, walking.	3 - 6 METs 64 - 76% HR_{max} 40 - 59% HHR 46 - 63% VO_{2max} RPE 12 - 13
VIGOROUS	Aerobic activity during which a conversation cannot be maintained; an intensity that may last up to 30 mins.	Jogging, aerobics, fast bicycling, resistance training, competitive sports.	6 - 9 METs 77 - 95% HR_{max} 60 - 89% HHR 64 - 90% VO_{2max} RPE 14 - 17
NEAR MAXIMAL TO MAXIMAL	Activity that typically cannot be sustained for more than 10 minutes.	Sprinting periods of competitive team sports activity.	≥ 9 METs ≥ 96% HR_{max} ≥ 90% HHR ≥ 91% VO_{2max} RPE ≥ 18

TEE in young and growing athletes is composed of four contributing factors (a) the basal metabolic rate (BMR); the amount of energy required to main normal homeostatic physiological functions in a rested, fasted and thermoneutral state, (b) the thermic effect of food (TEF); the energy cost of digestion, transport, absorption and storage of food, (c) activity energy expenditure; including both energy expended during organised sport, exercise or training (physical activity - PA) and non-exercise activity thermogenesis (NEAT) and (d) energy expended due to growth. BMR constitutes ~45-70% of total energy intake (FAO/WHO/UNU, 2005).

2.4.1.1 Predictive equations for calculation of BMR

Due to the accessibility, cost, and equipment requirements of measuring BMR, predictive equations are widely used. TEE can then be calculated using algorithms based on the BMR and using either a measured or assumed physical activity level (PAL). Although there is high metabolic variability within and between individuals (Petrie, Stover, & Horswill, 2004), the difficulties in measuring BMR or resting metabolic rate (RMR) (Burke, Lundy, Fahrenholtz, & Melin, 2018) mean equations are used widely in children and adolescents and are considered reliable (FAO/WHO/UNU, 2005). However, some caution is needed due to the assumption that weight is reflective of body composition (Carpenter, Pencharz, & Mouzaki, 2015). In adults, BMR increases proportionally to body mass (BM), particularly lean body mass (LBM) (Ravussin and Bogardus, 1989). This is the same in children but due to growth, BMR per unit of BM decreases as children move towards peak height (Garn, Clark, & Harper, 1953).

Many different predictive equations for BMR are regularly used in athletic populations and the benefits of each have been widely discussed (Flack, Siders, Johnson, & Roemmich, 2016; Oliveira *et al.*, 2021; Schofield, Thorpe, & Sims, 2019; Tinsley, Graybeal, & Moore, 2019) and their use in athletic populations is not always recommended (Schofield*, et al.*, 2019). In the general population, the most commonly used equations are the Harris Benedict (Harris and Benedict, 1919) and Schofield Equation's (Schofield, 1985) which both include equations split

by age and gender and are based on BM rather than a measure of free fat mass (FFM). It has been suggested that all predictive equations that use BM will underestimate BMR in athletes due to their higher levels of metabolically active FFM (Schofield*, et al.*, 2019). However, Hannon, Carney*, et al.* (2020) comparing equations in adolescent male footballers (tier 3/4) found that all the equations studied gave values that differed from the measured metabolic rates and that there was no benefit in using existing equations that took body composition into account. Use of equations relying on FFM is also controversial due to the inherent errors and inaccuracy in measuring body composition (Pontzer *et al.*, 2021).

The Harris Benedict Equations were originally based on indirect calorimetry data from 239 Caucasian's (136 men and 103 women) with low to normal BMI (Harris and Benedict, 1919) making them less relevant for use in other populations. To address this weakness, the Schofield Equations were developed using a meta-analysis of 7,173 data points with mixed ethnicity, weight profiles and ages (Schofield, 1985). Schofield equations have been found to be valid in children and adolescents (Rodriguez, Moreno, Sarria, Fleta, & Bueno, 2002), but can slightly overestimate BMR (Waterlow and Schürch, 1996). The Schofield Equations were later modified (Henry, 2005) giving the Oxford Equations, removing some of the original data that had been found to be unsound. These modified equations are found to be more accurate (Weijs, 2008). Estimates of BMR using the Oxford Equations (Henry, 2005) are generally 3-4% lower than using the Schofield Equations and they are currently used by the World Health Organisation (WHO) and Scientific Advisory Committee on Nutrition (SACN). The Oxford Equations for females aged 10-18 yr is given as Equation 2.5.

Equation 2.5 Oxford Equation for estimation of BMR. Adapted by Henry, 2005

BMR = (9.40 * mass (kg)) + (249 * height (m)) + 462

Oxford Equations have not been specifically validated for a female athletic population. Reale, Roberts, Lee, Bonsignore, & Anderson (2020) assessing the accuracy of current equations in a mixed group of adolescent athletes found that equations that differentiated between sexes were more accurate for estimating BMR than single equations and that out of those tested only the Schofield Equation (Schofield, 1985) could be considered appropriate for use within this group. Hannon, Carney*, et al.* (2020) and Reale*, et al.* (2020) have developed new equations for specific use in athletic adolescent populations but they have yet to be validated outside their own studies. Hannon, Carney*, et al.* (2020) was designed for male adolescent academy football players and so would not be appropriate for use in adolescent female athletes but the Reale*, et al.* (2020) equation was split by gender and also investigated using developmental age as a factor. The Reale Equation was shown to outperform the Schofield Equation in predicting measured RMR (Reale*, et al.*, 2020), but the difference was relatively small and may have been even smaller if they had compared the results with the Oxford Equations, which was not investigated in this study. The sample size and age span were also small, including just 29 female participants aged 14.1-18.5 yr, which may explain why there was no benefit in using developmental age, all of the participants being likely to be post-pubescent (Reale*, et al.*, 2020).

2.4.1.2 Physical Activity (PA)

The component of TEE corresponding to physical activity level is highly variable. It usually accounts for ~25-50% of energy expenditure but can account for up to 75% total energy (Westerterp, 1998). Total physical activity includes both the energy expended during organised training and competition and the energy used for all normal daily activities (Non-Exercise Activity Thermogenesis (NEAT). Multiple measures may be necessary to gain information on all aspects of an individual's activity, with direct observation, self-report diaries, accelerometers and HR monitors all having a role. (Sylvia, Bernstein, Hubbard, Keating, & Anderson, 2014).

2.4.1.3 Physical Activity Levels (PAL)

PAL is an estimation of physical activity types derived from experimental studies; the energy costs of activity being expressed as multiples of BMR based on measured activity levels and exercise energy expenditure (EEE) (FAO/WHO/UNU, 2005) as shown by the Equation 2.6.

Equation 2.6 Equation used for the calculation of PAL from TEE and BMR

PAL = TEE / BMR. Where PAL is the Physical Activity Level, TEE = Total energy expenditure and BMR = Basal Metabolic Rate.

PAL values of between 1.50 and 1.75 are recommended for moderately active adolescent females (FAO/WHO/UNU, 2005; Torun, 2005). Values of 1.50 – 1.85 are suggested for adolescent boys and high PAL values (1.5 - 2.2) have been calculated for active football academy players (Hannon, Parker*, et al.*, 2020). Studies using doubly labelled water (DLW) have found substantially higher PAL values in long-term trained women compared to sedentary women doing the same level of intensive training (Withers, Smith, Tucker, Brinkman, & Clark, 1998). However, Carlsohn *et al* (2011) found that although active adolescents were involved in high amounts of training, DLW observations showed PAL was no different from age matched controls (average age 15.6 yr) and both the active and control groups had activity levels below those suggested for adult athletes by the WHO. Carlsohn *et al.* (2011) concluded that the results showed adolescent athletes had far lower leisure time activity, being more sedentary in the time between training, lowering the difference in total activity between them and the controls and this type of compensatory behaviour has also been shown in adult athletes (Weiler, Aggio, Hamer, Taylor, & Kumar, 2015). Tables of PAL values are given in FAO/WHO/UNU (2005) and SACN (2008) / Report 41. In girls age 9 – 18 yr, a PAL > 1.0 < 1.4 is assessed as sedentary, > 1.4 < 1.6 as low active, > 1.6 < 1.9 as moderately active and > 1.9 < 2.5 as very active (FAO/WHO/UNU, 2005).

2.4.1.4 Physical Activity Questionnaires

In order to better understand the 'usual' activity being done within an adolescent population and the context of that activity, self-report questionnaires are a convenient and affordable method of data collection (Hidding, Chinapaw, Van Poppel, Mokkink, & Altenburg, 2018).

The physical activity questionnaire (PAQ) is a well validated activity questionnaire that has been adapted for use in both child (PAQ-C) and adolescent (PAQ-A) populations (Kowalski, Crocker, & Donen, 2004; Kowalski, Crocker, & Faulkner, 1997) and for use in the UK (Aggio, Fairclough, Knowles, & Graves, 2016; Voss, Ogunleye, & Sandercock, 2013). The PAQ has been widely used to assess term time activity during adolescence (Aggio*, et al.*, 2016; Benítez-Porres, Alvero-Cruz, Sardinha, López-Fernández, & Carnero, 2016; Hidding*, et al.*, 2018; Janz, Lutuchy, Wenthe, & Levy, 2008; Kowalski*, et al.*, 2004; Marasso, Lupo, Collura, Rainoldi, & Brustio, 2021; Montgomery *et al.*, 2021; Stewart and Lim, 2017; Thomas and Upton, 2014). The original PAQ-C has been specifically modified and validated for secondary school children in the UK by adapting the sports included (Montgomery*, et al.*, 2021; Stewart and Lim, 2017; Voss*, et al.*, 2013; Welk and Eklund, 2005) and including sections on morning break and before school activity (Aggio*, et al.*, 2016). The PAQ-C is better adapted than the PAQ-A for the UK, as children in full time education in the UK continue to have a morning break throughout adolescence. Kolimechkov, Petrov, & Alexandrova (2017) recommended cut offs for the different physical activity levels with a PAQ-C summary value of <2.5 being taken as low activity, >2.5 - 3.5 as moderate activity and >3.5 as high activity. Total daytime activity is found to be highly variable but studies using the PAQ-C in UK school children have consistently found activity levels within the moderate activity band (Kolimechkov*, et al.*, 2017; Voss*, et al.*, 2013). PAQ-C values in UK school girls have been found to be negatively correlated to age (Voss*, et al.*, 2013). Official figures within the UK show that 44.9% of children, 42.7% of girls in England meet the current government guidelines of doing at least 60 minutes

of sport or PA of moderate or high intensity every day (ONS 2021), which would be consistent with these findings.

The main limitation of self-report surveys is that individuals rarely accurately recall the intensity, frequency and duration of the PA they do (Sallis and Saelens, 2000). Another possible limitation of using a questionnaire is that children are sometimes found to have difficulties in understanding questions and accurately recalling activities (Janz*, et al.*, 2008), leading to both overestimates and underestimate of the overall PA level. There is an extra chance of over-reporting due to a social desirability bias in young athletes (Adams *et al.*, 2005). An alternative approach to a self-reported measure is the objective monitoring of PA using accelerometers to directly measure PA levels (Marasso*, et al.*, 2021).

2.4.1.5 Accelerometers

An accelerometer that has been regularly used to quantify PA in a range of populations is the GeneActiv, which is an unobtrusive tri-axial accelerometer which can be worn on the wrist resembling a wristwatch. It can be easily used during training, matches and recovery sessions (Salagaras *et al.*, 2021), is validated for use in young people (Phillips, Parfitt, & Rowlands, 2013) and its use has been found to be popular with adolescent girls (Sebire *et al.*, 2019). Wrist worn activity monitors have better compliance and wear time in young populations than early models which were predominantly worn around the hip or waist (Fairclough *et al.*, 2016; Ward *et al.*, 2011).

GeneActiv accelerometers record acceleration data with a range up to ± 8 gravitational units (g's) at a sampling frequency between 10 and 100 Hertz (Hz) in 10 Hz increments. Raw measured output data (g's) has been validated using a mechanical shaker (Esliger and Tremblay, 2007) and calibration of prediction models to estimate EE and time spent in different PA intensity levels have been developed for children and adolescents (Duncan, Wilson, Tallis,

& Eyre, 2016; Hildebrand, Hansen, Van Hees, & Ekelund, 2017; Phillips*, et al.*, 2013; Rowlands *et al.*, 2018; Schaefer, Nigg, Hill, Brink, & Browning, 2014). Phillips*, et al.* (2013) developed cut off points for using a GENEA in youth, the GENEA being a forerunner to the current GeneActiv with identical in functionality. A sample of 44 children (10.9 ± 1.9, range 8 – 14 yr) completed eight activities whilst wearing monitors on both wrists and on the right hip. Cut offs were developed using receiver operating characteristics split into four intensities: sedentary (< 1.5 MET), light (1.5 – 2.99 MET), Moderate (3 – 5.99 MET) and vigorous (> 6 MET). The regression equations used to predict EE in children and adolescents were developed by Hildebrand, Van-Hees, Hansen, & Ekelund (2014).

The majority of studies using GeneActiv accelerometers to assess activity levels in adolescence have used set cut-offs to assess the amount of moderate to vigorous physical activity (MVPA). Sanders *et al.* (2019) using wrist worn GeneActiv in US adolescents (13-18 yr) and found they did an average of 53 minutes MVPA a day, with around a third meeting the health guidance to do >60 minutes a day. Two studies done in the UK, Scott *et al.* (2017) and Rowlands*, et al.* (2018) found adolescent girls did 30 minutes and 45 minutes of MVPA a day respectively, lower than the US study. However, comparison is difficult as each study used slightly different cut-off points and methods of calculation. Comparison with earlier studies is also difficult as many used hip or waist mounted accelerometers and wrist accelerometers capture a greater range of movement particularly whilst seated (Sanders*, et al.*, 2019).

No studies have been published using GeneActiv in adolescent athletes and the majority of studies in athletes have used the device to track sleep rather than PA (Seshadri *et al.*, 2019). Salagaras*, et al.* (2021) assessed the utility of using GeneActiv to estimate EE in elite Australian football (AFL) players (tier 3/4) and concluded that the EE calculated was sound and in agreement with other studies in AFL. Weiler*, et al.* (2015) looking at sedentary behaviour amongst elite professional footballers (tier 4/5) used GeneActiv to monitor activity outside training and match time and classifying time into each activity intensity using the MET

cut-offs given in Table 2.6. During waking non-training hours, players were found to spend 79% sedentary; sitting, lying down, watching television, passive transportation, using a computer or playing video games. Siddall *et al.* (2019) assessing use of GeneActiv in a military setting over 10 days found comparative EE to that calculated using DLW. Physical training sessions during the data collection period comprised of circuit training, running and hill sprints, resistance training and a day where participants were involved in their own sports (including horse riding, hockey, basketball, and athletics). Both the physical training sessions and individual sport sessions would involve similar patterns of movement and movement intensity to those completed during team sport training and competition.

Validation studies of wearable devices regularly find an underestimation of energy expenditure compared to DLW, with the underestimation ranging from 100 – 600 kcals (Burke, Melin, & Lundy, 2018; Murakami *et al.*, 2016). It is thought that accelerometers may underestimate energy expenditure at more vigorous exercise levels (Abel *et al.*, 2008) and that accuracy of measurement may be improved by simultaneously measuring vigorous exercise (Burke, Melin*, et al.*, 2018) using a method that accounts for anaerobic as well as aerobic metabolism.

2.4.1.6 Metabolic power

In order to overcome some of the challenges of estimating the EE associated with intermittent team sports Di Prampero *et al.* (2005) proposed a theoretical model to estimate energy expenditure during match play using the cost of running uphill at constant velocity as a basis for calculating metabolic power. The assumption being that the energy cost of accelerating on the flat is equivalent to running at a constant velocity up an equivalent slope, which allows metabolic power output to be calculated at any given moment (Di Prampero*, et al.*, 2005; Di Prampero, Botter, & Osgnach, 2015).

Table 2.7 Metabolic power characteristics for position in U17 and U21 elite (tier 3/4) female hockey players Vescovi (2016a) and elite (tier 4/5) male adult players Polglaze, et al. (2017).

	Mean power ($W \cdot kg^{-1}$)	Energy Cost ($kJ \cdot kg^{-1}$)	Energy Cost ($kcal \cdot kg^{-1}$)
Female U17 team	10 ± 1 (10– 11)	23 ± 8 (20 – 26)	6 ± 2 (5 – 6)
Female U21 team	11 ± 1 (10 – 1)	27 ± 5 (25– 30)	7 ± 1 (6 – 7)
Female Forwards (U17/21)	11 ± 1 (10– 11)	19 ± 5 (16 – 22)	5 ± 1 (4 – 5)
Female Midfield (U17/21)	11 ± 1 (10 – 11)	27 ± 8 (24 – 31)	7 ± 2 (6 – 8)
Female Backs (U17/21)	7 ± 1 (9 – 10)	29 ± 4 (26– 31)	7 ± 1 (6 – 8)
Male International team (27.5 ± 3.1 y)	11 ± 1	32 ± 34	8 ± 1
Male Forwards	11 ± 1	30 ± 3	7 ± 1
Male Midfield	12 ± 1	32 ± 3	8 ± 1
Male Backs	11 ± 1	33 ± 4	8 ± 1

There are no studies in adolescent athletes but calculation of EE using metabolic power has been extensively used in adult football (Gaudino *et al.*, 2014; Gaudino *et al.*, 2013; Manzi, Impellizzeri, & Castagna, 2014; Osgnach, Poser, Bernardini, Rinaldo, & Di Prampero, 2010), rugby (Kempton, Sirotic, Rampinini, & Coutts, 2015) and Australian football (Coutts *et al.*, 2015). In hockey, Vescovi (2016) estimated EE using a metabolic power calculation in U17 and U21 Canadian female Internationals (tier 3/4) and Polglaze, Dawson, Buttfield, & Peeling

(2017) used the same method to analyse the EE in Australian elite (tier 4/5) male players (age 27.5 ± 3.1 yr), these values are given in Table 2.7. Female U21 players covered greater distances, relative distances and used higher maximal power than U17 players. Energy expenditure for played match time (using mean mass) was 269 – 360 kcal for U17 and 375 – 451 kcals for U21 players (Vescovi, 2016). Forwards had a lower metabolic power and EE than midfield players or backs. Time on the pitch is not given by Vescovi (2016) but the $m \cdot min^{-1}$ and distances given imply forwards were only on the pitch for ~30 minutes of match time, whereas backs played ~50 minutes and midfield players ~42 minutes which explains this difference. In male adult internationals, Polglaze*, et al.* (2017) found the same relationship between positions, with forwards having lower metabolic power and EE but lower pitch time than midfield or defensive players (backs). EE for played match time (using mean mass) was 585 ± 69 kcal, notably higher than the female U17 and U21 players.

Using metabolic power is now widely regarded as the best way of estimating EE during exercise, being more accurate than any of the possible alternatives (Di Prampero and Osgnach, 2018; Highton, Mullen, Norris, Oxendale, & Twist, 2017; Polglaze, Dawson, & Peeling, 2016) and the modern algorithms used with GPS and activity trackers are increasingly accurate (Di Prampero and Osgnach, 2018; Polglaze*, et al.*, 2016). However, Buglione and Di Prampero (2013) and Stevens *et al.* (2015) found that metabolic power calculations overestimate EE during constant velocity running and underestimate the cost of high-intensity multi-directional movement patterns. Hockey is a highly intermittent game with a very high number of motion changes which may mean these calculations are less accurate. Spencer *et al.* (2004) (tier 4/5) and Paun (2008) (tier 4) reported between 750 and 900 motion changes per game in male adults; a change in activity on average every 5.5 seconds and Macleod*, et al.* (2007) (tier 3/4) reported 960 ± 272 motion changes in adult female players equating to an activity change every 3 s. It is also worth noting that there has been no validation studies done in hockey or on using metabolic power calculations on AstroTurf (Vescovi, 2016) and that the model is unlikely to take into account the added cost of dribbling in hockey, which is known to

increase oxygen consumption by 15% compared to running at the same speed (Reilly and Seaton, 1990).

EE values calculated from metabolic power in male football, 61.12 $kJ \cdot kg^{-1}$ (Osgnach*, et al.*, 2010), Australian football 57 to 60.8 $kJ \cdot kg^{-1}$ (Coutts*, et al.*, 2015) and male rugby league 25.7 to 43.3 $kJ \cdot kg^{-1}$ (Kempton*, et al.*, 2015) are all higher than found in hockey. This difference has been explained by the shorter games, smaller playing area and unlimited substitution (Polglaze*, et al.*, 2017) but the lack of validation in hockey and possible limitations of the current EE from metabolic power algorithm cannot be ruled out as another factor.

2.4.1.7 Heart Rate (HR)

The energy cost of individual exercise sessions; training or matches can be important to design optimal fuelling strategies. As HR has a linear relationship with oxygen uptake at sub-maximal exercise intensities (Garcia, Santo, Garcia, & Nunes, 2005), it can be used to estimate energy expenditure using a previously laboratory measured individual relationship between HR and VO_2 and the assumption that 1 litre O_2 = 5.0 kcal and 1 MET = 3.5 $mlO_2 \cdot kg^{-1} \cdot min^{-1}$ (Mcardle, Katch, & Katch, 2003). Spurr *et al.* (1988) compared 24 hours of EE using direct calorimetry with HR and found deviation between +20 and -15% making the method inappropriate for use at the individual level but that group data was representative and the method has been used to calculate EE in football (Bangsbo, 1994; Coelho *et al.*, 2010; Garcia*, et al.*, 2005), netball (Rumbold, Gibson, Allsop, Stevenson, & Dodd-Reynolds, 2011) and hockey (Konarski, 2009). The main limitation of this method is the almost flat slope at the low levels of EE, where very slight movement or changes in emotion can influence HR but there is limited effect on oxygen uptake. Konarski (2009) quantified that male adult hockey players (tier 3) expended 894 ± 223 kcals (12.4 ± 3.1 $kcal \cdot kg^{-1}$) during an outdoor match notably higher than measured using metabolic power calculations by Polglaze*, et al.* (2017) (tier 4/5) but no detail was given on pitch time making comparison difficult. No studies have been published in adolescent hockey players but Rumbold, Gibson, Allsop*, et al.* (2011) used HR

to measure energy expenditure in adolescent netball players (age 14.7 ± 0.9 yr) as 344 ± 43 kcals (5.8 ± 0.7 kcal·kg^{-1}) during a 47 minute netball exercise protocol.

2.5 Energy Intake (EI) and Nutritional Adequacy

The main concern for practitioners working with adolescent athletes should be to ensure that all their nutritional requirements are met (Desbrow *et al.*, 2014). Particular care is important as there are key anatomical, physiological and metabolic differences between child or adolescent athletes and adults (Hannon, Close*, et al.*, 2020; Hannon*, et al.*, 2019) and there is not always the research available to formulate strong advice (Desbrow*, et al.*, 2019). Adequate EI is of particular importance when making recommendations on protein intake. Sub-optimal EI causes endogenous protein to be used to maintain blood glucose preventing its use for its primary role (Desbrow, 2021b).

2.5.1 Adequate energy intake (EI) and Energy availability (EA)

Traditionally, it was advised that to maintain stable BM and promote positive training adaptations and competition performance, athletes should aim to be in energy balance (EB), with EI matching EE as shown in Equation 2.7. However, energy balance is a dynamic process, influenced by both internal and external factors including the composition, energy density, timing of intake, and the timing and intensity of exercise and energy balance can only be seen as a guide of EA or adequacy (Manore, 2021).

Equation 2.7 Equation for calculation of energy balance

EB = $E_{in} = E_{out}$ Where E_{in} = the energy metabolised (kcal·d^{-1}) (90-98% of energy consumed (Murphy, Wootton, & Jackson, 1993)) and E_{out} = Total energy expenditure (TEE) (kcal·d^{-1}). TEE = resting energy expenditure (RMR), Thermic effect of food (TEF), Exercise energy expenditure (EEE) and Non-exercise activity thermogenesis (NEAT).

Having an adequate EI to provide for EE both for basic body function and sports performance is a special concern for growing female athletes because of the risk of Relative Energy Deficiency in Sport (RED-S) (Logue*, et al.*, 2020; Mountjoy*, et al.*, 2014). EA for sport is defined by Equation 2.8. Use of EA as a measure of adequate EI is now the preferred measure of energy adequacy in athletes, being easily measured and under the behavioural control of the athlete (Manore, 2021). If low energy availability (LEA) is found, both EEE and EI are easily manipulated by the athlete or their coaches being easy to visualise and track (Burke, Lundy*, et al.*, 2018).

Equation 2.8 Equation for the calculation of energy availability

EA = (EI – EEE) / FFM

Where EI = energy intake, EEE = energy expenditure during exercise (minus any sedentary time) and FFM = fat free mass.

Laboratory studies in adult female athletes suggest optimum average EA, for healthy physiological function is 45 $kcal \cdot kg^{-1}FM \cdot day^{-1}$ (De Souza*, et al.*, 2014; Loucks*, et al.*, 2011; Mountjoy, 2018; Thomas, Erdman, & Burke, 2016). LEA availability for 4-5 days (10-30 $kcal \cdot kg^{-1}FM \cdot day^{-1}$) caused by dietary restriction and/or high training load reduces blood glucose levels, elevates cortisol, increases growth hormone and suppresses normal concentrations or pulsatility of metabolic hormones and reproductive hormones (Loucks*, et al.*, 2011). No research has been conducted in young female athletes but considering the greater relative energy demands due to ongoing growth and development, 45 $kcal \cdot kg^{-1} \cdot FM \cdot day^{-1}$ should be considered as the minimum required in this population (Hannon*, et al.*, 2019).

Due to the difficulty of the calculation of EA in the field, Nose-Ogura *et al.* (2019) and Edama *et al.* (2021) used the ACSM definition of LEA in adolescent athletes of having a body weight

<85% of ideal body weight and found strong correlations between calculated LEA and stress fracture risk or injury risk. Ideal body weight calculations are relatively accurate in young children, but less consensus is found in later adolescence (Phillips, Edlbeck, Kirby, & Goday, 2007).

2.5.2 Adequate energy intake in female athletes

Studies measuring EI of female athletes frequently report kilocalorie (kcal) intakes below EE particularly in sports where there is benefit in low body weight (Beals and Manore, 1998) or an emphasis on appearance (Sundgot-Borgen and Garthe, 2011; Sundgot-Borgen and Torstveit, 2004). EI is a special concern to female athletes because of the risk of Relative Energy Deficiency in Sport (RED-S). RED-S (previously known as the Female Athlete Triad) refers to the impaired physiological function, metabolic rate, menstrual function, reduced bone health, immunity, protein synthesis and cardiovascular health caused by relative energy deficiency and is now known to occur in men as well as women (Mountjoy*, et al.*, 2014). Insufficient energy (and carbohydrate) intake can compromise hormone patterns, leading to alterations in growth, impaired performance, decreased bone mineralization and increased injury (Rosenbloom, Loucks, & Ekblom, 2006). Hoch *et al.* (2009) investigating eating habits in female high school athletes (age 13 – 18 yr) found 78% had some symptoms of Female Athlete Triad and Hinton, Sanford, Davidson, Yakushko, & Beck (2004) examining nutrient intake and eating behaviour in collegiate athletes, including 165 female athletes (19.3 ± 1.2. yr) reported 70% of female footballers were actively restricting EI with the aim of losing weight. LEA may occur due to insufficient EI, a higher-than-expected EE or combination of the two (Beals and Hill, 2006).

Disordered eating is common in competitive sport and the highest risk of eating disorders is during adolescence, coinciding with sports specialisation and increased competition demands (Bergeron*, et al.*, 2015) as well as pressure from coaches, peers, parents and social media

(Stoyel, Delderfield, Shanmuganathan-Felton, Stoyel, & Serpell, 2021; Stoyel, Slee, Meyer, & Serpell, 2020). To succeed in elite sport, athletes require high levels of perfectionism, tolerance to pain and motivation which can also perpetuate the development of eating disorders (Stirling and Kerr, 2012), Restriction of EI is generally in the control of the athletes themselves (Deuster *et al.*, 1986) but it is not always deliberate (Beals, 2002). Low EI can be due to lack of knowledge and an individual can be unaware that their intake is below the level needed to fuel both training and normal body function (Beals, 2002; Beals and Hill, 2006). The daily schedule and living environment can also have a substantial impact on when athletes are able to eat and the type of foods that are available (Hinton*, et al.*, 2004).

2.5.3 Energy intake in female hockey players

There have only been four studies investigating nutritional adequacy which have included adult female hockey players, these are summarised in Table 2.8 Van Erp-Baart *et al* (1989) included nine female hockey players in a study of mixed elite (tier 4/5) athletes (24 yr) recording an average EI of 91-199 $kJ \cdot kg^{-1}$ (21.7 – 47.6 $kcal \cdot kg^{-1}$) but they did not look at EE in individual sports, or comment on whether this was thought to be adequate. All three US Collegiate studies concluded that energy and nutrient intake was lower than recommended across all the sports included but did not separate out hockey players (Nutter, 1991; Tilgner and Schiller, 1989; Van Erp-Baart, Saris, Binkhorst, Vos, & Elvers, 1989). All these studies were conducted before the main rule changes within hockey and before substantial changes within collegiate sport. Prior to this time little or no nutrition advice would be provided to these athletes, the first full-time registered dietitian was hired by an American University in 1994 (Hull *et al.*, 2016).

Wardenaar *et al* (2017) compared macronutrient intakes in 553 Dutch Elite athletes included 11 female hockey players (average age 18.5 yr) where average EI was 2091 ± 373 kcal (52.9% carbohydrate, 17.5% protein and 29.6% fat). Average intakes of carbohydrate 4.2 ± 0.5 $g \cdot kg^{-}$

[1] and protein 1.4 ± 0.1 $g \cdot kg^{-1}$ were reported and both lower than intakes recommended for adolescent athletes by Sports Dietitians Australia in their position statement (Desbrow*, et al.*, 2014) and for all ages by the American College of Sports Medicine (Thomas*, et al.*, 2016).

Table 2.8 Energy intake and percentage macronutrient distribution four studies including female hockey players (1989-91).

	Study population	Reported energy intake	Percentage Macronutrient Intake
Van Erp-Baart*, et al.* (1989)	Elite (tier 4/5) Dutch Hockey Players. n=9. 4d food diary	Energy 2151 kcal,	46% CHO, 19% PRO, 35% Fat
Tilgner and Schiller (1989)	USA College n=8. 3d food diary	Energy 1955 kcal,	47% CHO, 16% PRO, 39% Fat
Nutter (1991)	USA College n=9. 3d food diary	Energy 1581 kcal,	54% CHO, 15% PRO, 27% Fat
Nutter (1991)	USA College n=9. 3d food diary	Energy 1432 kcal,	54% CHO, 16% PRO, 30% Fat

2.5.4 Adequate energy intake adolescent athletes

Research in adolescent academy football players has found that junior male (Boisseau, Le Creff, Loyens, & Poortmans, 2002; Boisseau, Vermorel, Rance, Duché, & Patureau-Mirand, 2007; Briggs, Rumbold, Cockburn, Russell, & Stevenson, 2015; Iglesias-Gutiérrez *et al.*, 2005; Leblanc, Gall, Grandjean, & Verger, 2002; Naughton *et al.*, 2016; Ruiz *et al.*, 2005; Russell and Pennock, 2011) and female players (Braun, Von Andrian-Werburg, Schänzer, & Thevis, 2018; Clark, Reed, Crouse, & Armstrong, 2003; Gibson*, et al.*, 2011; Mullinix, Jonnalagadda, Rosenbloom, Thompson, & Kicklighter, 2003; Parnell, Wiens, & Erdman, 2016; Reed, De Souza, Kindler, & Williams, 2014) regularly fail to meet energy requirements and have carbohydrate intakes below optimal levels.

There is very little research on the intake and status of female adolescent athletes outside football, but negative EB has been found in female adolescent volleyball players (Beals, 2002;

Papadopoulou, Papadopoulou, & Gallos, 2002), adolescent sprint athletes (Aerenhouts, Deriemaeker, Hebbelinck, & Clarys, 2011; Aerenhouts, Hebbelinck, Poortmans, & Clarys, 2008), modern pentathletes (Coutinho, Porto, & Pierucci, 2016), 'talented' female adolescent team-sport athletes (Baker, Heaton, Nuccio, & Stein, 2013) and mixed pre-adolescent and adolescent Canadian athletes (Parnell*, et al.*, 2016).

The above female studies investigating nutritional adequacy have measured EI using estimated food diaries (Aerenhouts*, et al.*, 2011; Beals, 2002; Braun*, et al.*, 2018; Clark*, et al.*, 2003; Gibson*, et al.*, 2011; Mullinix*, et al.*, 2003; Papadopoulou*, et al.*, 2002; Reed*, et al.*, 2014), or self-report surveys (Coutinho*, et al.*, 2016; Parnell*, et al.*, 2016). Self-report diaries and predictive equations have also been used to estimate EE (Beals, 2002; Gibson*, et al.*, 2011; Mullinix*, et al.*, 2003). A major source of error during the assessment of nutrition status is misreporting in the dietary records and there is considerable uncertainty over the reporting of dietary intake in adolescent girls (Aerenhouts*, et al.*, 2008). Female participants regularly under-report EI by up to 37% (Black, 2000; Poslusna, Ruprich, De Vries, Jakubikova, & Van't Veer, 2009), adolescent girls under-report energy intake by between 20% and 30% (Bandini *et al.*, 2003; Bandini, Schoeller, Cyr, & Dietz, 1990; Bratteby, Sandhagen, Fan, Enghardt, & Samuelson, 1998; Livingstone *et al.*, 1992), with the level of underreporting increasing with age (Livingstone*, et al.*, 1992). In athletes, underreporting has been estimated to account for 10–45% of total EE (Magkos and Yannakoulia, 2003).

Self-report of physical activity also introduces a second possible bias (Garcia Roves 2014). As detail on BM change is rarely reported in this research, despite reported negative energy balance, it is hard to assess the accuracy of any deficit (Briggs, Rumbold*, et al.*, 2015; Galanti *et al.*, 2015).

2.5.5 Dietary Intake collection methods

Accurate dietary assessment is a challenge within sports nutrition with the potential for significant errors of validity and reliability within records (Burke, 2015). Food diaries are the most popular dietary assessment method used within athlete populations. A seven-day weighed food diary is considered the gold standard technique to assess accurate intake in both adults and children and is regularly used in validation studies of other dietary assessment methods. However, in practical settings having to weigh each individual component of everything eaten and left uneaten, can present an unrealistic burden on participants, researchers and/or practitioners and result in unrepresentative eating patterns and poor recording (Ortega, Pérez-Rodrigo, & López-Sobaler, 2015).

2.5.5.1 Self-report Estimated Food Diaries

Self-report estimated food diaries are easy to administer and are commonly used in athlete populations. Dietary information is commonly collected for three, four or seven consecutive days (Rutishauser and Black, 2002), to include both weekdays and days at the weekend, with athletes asked to record all foods and drinks consumed in real time. As well as the amount of food eaten, participants are asked to record brand names, recipes, preparation and cooking methods, to give greater accuracy to the dietary analysis (Mcpherson, Hoelscher, Alexander, Scanlon, & Serdula, 2000). Additional data regarding the time and location of consumption, parallel activity, and the presence of other people can also be useful for the interpretation of an individual's eating pattern and social context of diet (Leech, Worsley, Timperio, & Mcnaughton, 2015).

Livingstone and Robson (2000) found that accuracy of reporting in adolescent showed similar bias to underreporting in both weighted and estimated food records. However, there are ways in which accuracy can be improved. Livingstone*, et al.* (1992) reported that having a parent

checking the diaries improves the accuracy of the detail recorded and Briggs, Rumbold*, et al.* (2015) working with adolescent male academy footballers found that although an under-report still existed, this was minimal when a double pass method was used with the researcher or another adult going through the detail given with the individual before analysis. The accuracy of food diaries in adolescents deteriorates from age 11 to 14 yr (Bandini*, et al.*, 2003; Champagne, Baker, Delany, Harsha, & Bray, 1998) at the same time as the amount of parental assistance is reduced (Livingstone, Robson, & Wallace, 2004).

Accuracy of reporting can also be improved when strong instruction is given to the participants on the detail needed and guidance included on the estimation of portion sizes (Ortega*, et al.*, 2015). As part of the Roots Study, a 4-day food diary was designed that included a short questionnaire to aid the interpretation of entries (Goodyer, Croudace, Dunn, Herbert, & Jones, 2010) and to provide extra detail on core foods eaten regularly, (for example the type of milk or spread) and to inquire about non-food items such as dietary supplements (Goodyer, 2005). Including this extra detail allows food entries to be double checked against the answers given and for detail to be added where missing. The Roots Diary has been successfully used in adolescence studies (Corder *et al.*, 2013; Corder *et al.*, 2011).

The use of photographs to support estimated food diaries has also been shown to improve the accuracy of dietary assessment over traditional assessments (Boushey *et al.*, 2009) and when done conscientiously can increase accuracy of diaries to an equivalent level of 7-day weighed food diaries (Costello, Mckenna, Deighton, & Jones, 2017; Hutchesson, Rollo, Callister, & Collins, 2015; Martin *et al.*, 2012; Schap, Zhu, Delp, & Boushey, 2014). This method has been successfully used in adolescent groups (Costello*, et al.*, 2017; Hutchesson*, et al.*, 2015) and as 98% of young people (age 16-24) now have their own smart phone (Statista, 2021), digital dietary assessment tools are popular in this age group (Forster, Walsh, Gibney, Brennan, & Gibney, 2016). However, outside of professional sports teams General Data Protection Regulation (GDPR) can make use of this technique difficult.

The number of days over which information is collected needs to be carefully considered. The timeframe needs to be long enough to provide reliable information on usual food consumption but needs to be balanced against the likelihood of poor compliance (Ortega*, et al.*, 2015). In the general population, 3-4 day food diaries are considered adequate for investigating the intake of a group (Burke, 2015). Recording for periods longer than 4 consecutive days causes accuracy of recorded intakes to decrease (Artero *et al.*, 2011) both due to respondent fatigue and as individuals start to fill in the record retrospectively rather than in real time (Thompson and Subar, 2013). Accurate food diaries are known to require a high level of motivation (Johnson, 2002) and the level of motivation has been found to fall off as the number of days of data collection increases (Buzzard, 1998). Four-day food diaries have been assessed alongside gold-standard 7-day weighed records and are shown to give comparable results (Bingham, Borkan, & Quatromoni, 2015). Four-day diaries are the method used for the National Diet and Nutrition Survey in the UK (Whitton *et al.*, 2011). Investigation into the use of 24-hour recall for this survey showed that this method may prompt over-reporting of intake in adolescent girls (Stephen *et al.*, 2009) and this has also been found in other studies using 24-hour recall in this age group (Bel-Serrat *et al.*, 2016; Rumbold, Gibson, Stevenson, & Dodd-Reynolds, 2011).

2.5.5.2 National Diet and Nutrition Survey

The National Diet and Nutrition Survey (NDNS) is designed to assess the diet, nutrient intake and nutritional status of the general population aged 1.5 yr and over, living in private households in the UK and involves a rolling program of household consumption surveys (NDNS, 2014; NDNS, 2018; NDNS., 2016). As all adolescent British athletes living and training in the UK are part of this population, it is important to understand the dietary intake in this broader group. The latest published data shows that adolescent girls between 11 and 18 yr have the poorest diets of any age group, with low energy intakes, low fruit and vegetable consumption (2.8 portions·day$^{-1)}$, low fibre (14.1 g) and high consumption of saturated fat

(12.6% total food energy) and free sugar (14.4% total food energy) (NDNS, 2018; NDNS., 2016). The main source of free added sugar in adolescents was non-alcoholic beverages / soft drinks (33%), confectionary making up 21% (NDNS, 2018). Saturated fat, sugar, fruit, vegetables, and fibre intakes are often used as measures of diet quality (Biltoft-Jensen *et al.*, 2008; Carvalho, Dutra, Pizato, Gruezo, & Ito, 2014). In the latest NDNS, only 8% of adolescents (aged 11-18 yr) regularly met the 5-a-day recommendation for fruit and vegetables.

2.5.6 Macronutrient requirements adolescent athletes

The IOC consensus statement on training the elite child athlete defines a child athlete as "one who has superior athletic talent, undergoes specialist training, receives expert coaching and is exposed to early competition" (Mountjoy *et al.*, 2008) and from this definition many children and adolescents involved in competitive club or school sport, or selected for specialist training might be counted as 'elite' and so requiring special support. However, it is important to ensure that the initial focus in children and young athletes is on wellbeing (Mountjoy and Bergeron, 2015), the quality of their diet and health outcomes rather than on specialist advice based on performance (Bingham*, et al.*, 2015; Logue *et al.*, 2021). Although more common in sports that emphasise leanness, disordered eating behaviours and body dissatisfaction have been found in a wide variety of young athletes (Martinsen*, et al.*, 2010) and research has called for a more sensitive approach to how nutrition provision is given in young athletes (Ackerman *et al.*, 2020). Advice to young athletes should be food based, practical, achievable and specifically relevant to the demands of their sport (Bingham*, et al.*, 2015) and visual models such as those developed by Reguant-Closa, Harris, Lohman, & Meyer (2019) should be used to support the development of a 'food first' approach (Desbrow, 2021b).

2.5.6.1 Carbohydrate (CHO) intake and recommendations

The role of carbohydrate in team sport performance can be split into two main areas;

carbohydrate as part of the base diet and carbohydrate taken during or immediately after sport to aid performance or recovery. There is little evidence that the utilisation of carbohydrate in adolescent athletes differs substantially from that of adults (Desbrow and Leveritt, 2020) and as in adult athletes, the duration and intensity of exercise sessions will determine carbohydrate requirements, with the current recommendation being 'to fuel for the work done' (Impey *et al.*, 2018). These calculations may be more complicated during childhood and adolescence, as developing athletes are often involved with numerous organisations within a single sport (school, club, regional, national) and can be competing in multiple sports (Desbrow, 2021b).

Greater glycogen stores enhance exercise performance in adults (Sherman, Costill, Fink, & Miller, 1981). Muscle glycogen concentration decreases during team sport matches (Ekblom, 1986; Krustrup, 2005; Mohr, Krustrup*, et al.*, 2003), and low muscle glycogen is linked to increasing levels of exercise fatigue, a reduction in the distance covered and running speed in the second half of matches (Ekblom, 1986). Young athletes, particularly pre-pubertal athletes have less muscle mass and lower glycogen stores than adults (Ekblom, 1986; Krustrup, 2005; Mohr, Krustrup*, et al.*, 2003) and due to the reduced muscle glycogen stores, exogenous sources of carbohydrate are of increased importance during high intensity exercise bouts (Jeukendrup and Cronin, 2011). Adolescent athletes are found to utilise lower absolute amounts of exogenous glucose than the values reported in adults (Riddell, Bar-Or, Hollidge-Horvat, Schwarcz, & Heigenhauser, 2000) but exogenous carbohydrate utilisation has a greater relative contribution to TEE (Riddell*, et al.*, 2000; Timmons, Bar-Or, & Riddell, 2003). Exogenous carbohydrate taken before or during intensive exercise is beneficial as it spares glycogen stores and this sparing effect may be greater in children (Montfort-Steiger and Williams, 2007). Whether carbohydrate intake improves team-sport performance in adolescents is uncertain; carbohydrate intake has been shown to improve endurance capacity during high-intensity shuttle running (Phillips, Turner, Gray, Sanderson, & Sproule, 2010), but neither a carbohydrate rich snack taken before prolonged exercise or a drink taken intermittently during prolonged exercise has been found to improve cycling performance in

adolescents (Montfort-Steiger and Williams, 2007). However, carbohydrate ingestion has been linked to increased skill in young basketball players (Dougherty, Baker, Chow, & Kenney, 2006), gymnasts (Batatinha *et al.*, 2013) and American football players (Smith, Lee, Dobson, Roberts, & Jeukendrup, 2013). Maintaining adequate glucose to fuel the brain for attention and decision making has been identified as being important in high-speed endurance team sports in adults and carbohydrate intake during games beneficial for skills performance (Winnick *et al.*, 2005). Current recommendations for carbohydrate intake during exercise in young athletes are the same as those in adults. During moderate-to-high intensity exercise lasting longer than 60 minutes, the advice is to consume 30-60 $g \cdot h^{-1}$ (<1 $g \cdot min^{-1}$) (Desbrow*, et al.*, 2014; Desbrow, 2021a).

After exercise, carbohydrate intake is recommended in adult athletes to fully replenish glycogen stores and it is likely that glycogen resynthesis is greatest in the first hour after exercise (Ivy, Katz, Cutler, Sherman, & Coyle, 1988). No studies have been undertaken in adolescent athletes, but the current advice is the same as for adults with 1.2 $g \cdot kg^{-1} \cdot h^{-1}$ of high glycaemic index (GI) carbohydrate recommended in the 2 hours immediately post exercise (Hannon, Close*, et al.*, 2020).

As young athletes may be training and competing in a variety of sports, advice regarding daily carbohydrate intake will be highly personalised. However, the current general advice is to consume between 3 and 10 $g \cdot kg^{-1} \cdot d^{-1}$ (Desbrow, 2021b; Hannon, Close*, et al.*, 2020; Naughton*, et al.*, 2016). Baker*, et al.* (2013) and Wardenaar *et al.* (2017) analysed dietary intake in a group of mixed adolescent skill, strength and team sport athletes and found the most common shortfall in nutrient intake across both sexes was carbohydrate. Lower than recommended carbohydrate intake has also been shown in adolescent male (Iglesias-Gutiérrez*, et al.*, 2005; Ruiz*, et al.*, 2005) and female football players (Burke, Hawley, Wong, & Jeukendrup, 2011; Rodriguez, 2009; Thomas*, et al.*, 2016). Leblanc et al. (2002) demonstrated that although average carbohydrate intakes in adolescents male football

players (age 13 to 16 yr) increased as body mass increased, carbohydrate intake per body mass did not increase (Leblanc*, et al.*, 2002) which suggests achieving adequate carbohydrate intake could be more of a problem in older adolescents. No corresponding studies have been undertaken in female athletes, adolescent female athletes or female team sports. In the UK 2014 National Diet and Nutrition Survey (NDNS), mean intakes of total carbohydrate as a percentage of total dietary energy were 51-52% in children over 4 yr old (NDNS, 2014). This is broadly in line with the current population advice but breakdown of the different types of carbohydrates shows that girls aged 10-18 yr have the poorest diet composition of any age group or gender, with very low fibre and high sugar intakes and only 7% reaching the target of five fruit or vegetables a day (NDNS., 2016). The current recommended fibre intake in 11-16yr old adolescents is 25g/day and for free sugars is <5% of total energy intake in all age groups (NDNS, 2018).

Excess intake of sugar as part of sport nutrition recommendations is common in all athletes and the use of refined carbohydrate containing sports drinks is particularly common in children (Rodriguez, 2009; Schneider and Benjamin, 2011). Excess intake of high energy foods can both unbalance the diet and substantially increase the risk of tooth decay and weight gain (Schneider and Benjamin, 2011). Active children and adolescents using sports drinks or foods appropriately are considered at low risk of unwanted fat accumulation (Mundt *et al.*, 2006) but their use must be planned in the context of training and match demands (Holway and Spriet, 2011) which often they are not. Female adolescent sprint athletes who consumed soft drinks had higher body fat percentages than non-consuming athletes (Aerenhouts*, et al.*, 2008). Consumption of easily digested sugary carbohydrates may also compromise fibre intakes. Low fibre intakes have been found in nutritional surveys of young professional football players (Russell and Pennock, 2011) and female athletes (Heaney, O'connor, Gifford, & Naughton, 2010).

2.5.6.2 Fat intake and recommendations

Younger athletes have been shown to have a greater reliance on fat as a fuel source during exercise than adults (Bar-Or, 2000). This is reflected in the respiratory exchange ratio during exercise (Martinez and Haymes, 1992; Riddell, Bar-Or, Wilk, Parolin, & Heigenhauser, 2001; Timmons*, et al.*, 2003), higher plasma free glycerol (Má Ek and Vavra, 1981) and free fatty acids concentrations (Delamarche *et al.*, 1992; Hebestreit, Mimura, & Bar-Or, 1993) after prolonged exercise, (Hebestreit and Meyer, 1996). The development of 'adult-like' metabolic patterns occurs during mid to late puberty, with a gradual change from early to mid to late puberty in both respiratory exchange ratio and lactate (Stephens, Cole, & Mahon, 2006). However, despite the evidence that children are better adapted to use fat as fuel during exercise, there is no evidence of a performance benefit of high fat diets or of fat eaten before or during sport in young athletes (Burke, Millet, & Tarnopolsky, 2007). There are also no published studies in adolescent athletes on the role of intramuscular triacylglycerols in exercise performance (Bergman *et al.*, 2010) or how training with low carbohydrate intakes might enhance the use of fats as a fuel (Hawley, 2011) despite the interest in adult athletes. Current advice in adolescent athletes is that fat consumption should be in line with current public health guidelines (30-35% EI), including recommending unsaturated fats from plant sources and fish and limiting the intake of saturated fats (Desbrow*, et al.*, 2014). Ingestion of carbohydrate before and during exercise alters substrate use in male adolescents, substantially reducing fat utilisation from 32% to 18% (Riddell*, et al.*, 2000). If fat is the preferred fuel source due to higher fat oxidation rates in children, supplementary carbohydrate may disrupt this mechanism (Montfort-Steiger and Williams, 2007) and act to ameliorate performance gains. This research has not been done in female adolescent athletes, but as fat utilisation is higher in women (Venables, Achten, & Jeukendrup, 2005), the effect may be greater.

The fat recommendation for adult athletes is 20-25% of total daily energy intake (Maughan and Shirreffs, 2011; Rodriguez, 2009) and dietary fat intakes greater than 35% are not

recommended as it can compromise carbohydrate intake (García-Rovés, García-Zapico, Patterson, & Iglesias-Gutiérrez, 2014) or contribute to excessive weight gain (Je Quier, 2001). High fat diets increase intramuscular triacylglycerol concentrations while decreasing glycogen levels within muscle (Spriet, 2014). Acute excessive fat intake in children and adolescents can also result in postprandial oxidative stress, which is associated with impaired vascular and metabolic functioning and may increase risk of later life cardiovascular disease (Bloomer, Kabir, Marshall, Canale, & Farney, 2010). Low fat intakes are also not recommended. Gerlach, Burton, Dorn, Leddy, & Horvath (2008) found that injured runners consumed significantly less total fat and obtained a lower percentage of total calories from fat than non-injured runners, even after being adjusted for total EI. Low fat intake has also been linked to low energy density diets, increased risk of menstrual dysfunction and female athlete triad or RED-S (Reed *et al.*, 2011).

Research in young male football players has demonstrated fat intake to be higher than that recommended for athletes with intakes of 29-38% total energy (Boisseau*, et al.*, 2002; Briggs *et al.*, 2015; Caccialanza, Cameletti, & Cavallaro, 2007; Iglesias-Gutiérrez*, et al.*, 2005; Leblanc*, et al.*, 2002; Rico-Sanz, 1998; Ruiz*, et al.*, 2005; Russell and Pennock, 2011). There are fewer studies in female adolescent athletes, but adolescent female football players have also been shown to have intakes ranging from 29-30% (García-Rovés*, et al.*, 2014; Heaney*, et al.*, 2010) and high intakes were also found for young female rugby sevens players (Wardenaar*, et al.*, 2017), track and field athletes (Aerenhouts*, et al.*, 2008; Heaney*, et al.*, 2010), netball (Heaney*, et al.*, 2010), volleyball (Papadopoulou*, et al.*, 2002) and hockey players (Wardenaar*, et al.*, 2017). Gibson*, et al.* (2011) stated that 21.2% of elite (tier 3) adolescent female football players had fat intakes below recommended levels but recorded mean fat intake at 29.9% of EI. Although this is considered lower than recommended in the general population, it is higher than would be recommended in athletes (Otten, Hellwig, & Meyers, 2006). The NDNS 2016 recorded high total fat intake and higher than recommended saturated fat intake in all age groups of the British population (NDNS., 2016). In age 11-18 yr,

total fat intake was found to be 33.6% of EI and saturated fat 12.6% (NDNS., 2016). UK Health Recommendation is for fat to make up a maximum of 35% EI and saturated fat 11%.

2.5.6.3 Protein intakes and recommendations

High quality protein intake, containing a good mix of essential and branch chain amino acids is crucial for providing the building blocks for muscle hypertrophy and repair (Burd, Beals, Martinez, Salvador, & Skinner, 2019). This is particularly important for growth and development in adolescent athletes to enhance responses to exercise training (Tipton and Wolfe, 2004). During peak growth, increases in lean body mass can be as high as 2.3 g/day in females (Forbes, 1964), with increases in active adolescents being higher than sedentary individuals (Baxter-Jones, Eisenmann, Mirwald, Faulkner, & Bailey, 2008). The WHO recommends protein intakes of 0.8 - 0.9 $g \cdot kg^{-1}$ of body mass from age 3 to 18 yr for non-active to moderately active individuals (WHO/UN, 2007). As in adults, this level of protein intake has been shown as inadequate for adolescent athletes (Boisseau*, et al.*, 2007). Nitrogen balance studies have shown positive balance is achieved with dietary protein intakes of 1.4-1.6 $g \cdot kg^{-1} \cdot d^{-1}$ (Aerenhouts, Van Cauwenberg, Poortmans, Hauspie, & Clarys, 2013; Boisseau*, et al.*, 2002; Boisseau*, et al.*, 2007) and that the dietary protein requirements are similar to those of adults (Boisseau*, et al.*, 2007; Meyer*, et al.*, 2007). Adult athletes are known to have greater protein needs to maintain positive protein balance and support growth than sedentary individuals (Hawley, Tipton, & Millard-Stafford, 2006; Mettler, Mitchell, & Tipton, 2010; Phillips and Van Loon, 2011). As such higher recommended protein intakes of between 1.2 – 2.0 $g \cdot kg^{-1} \cdot d^{-1}$ have been proposed for highly trained or elite adult athletes (tier 3/4/5) (Thomas*, et al.*, 2016). Jeukendrup and Cronin (2011) concluded that the standard western diet has a protein intake that typically exceeds the RDA by 23-fold, providing more than the additional needs for adolescent athletes associated with exercise (Boisseau*, et al.*, 2007; Desbrow*, et al.*, 2014; Meyer*, et al.*, 2007). However, there is increasing evidence that it is the timing of protein intake that is important (Areta *et al.*, 2013; Mamerow *et al.*, 2014) and that the distribution of protein intake in both adult and junior athletes may be suboptimal (Anderson

et al., 2017; Gillen *et al.*, 2017; Naughton*, et al.*, 2016). Therefore, although traditional protein intake guidelines have been given relative to body mass, newer recommendations are given to highlight that muscle adaptation is maximised by ingesting protein consumed in meals spread across the day (Desbrow*, et al.*, 2014; Potgieter, 2013). The current ACSM recommendation is to consume 0.3 $g \cdot kg^{-1}$ after key exercise sessions and every 3-5 hours over multiple meals (Thomas*, et al.*, 2016). An intake of >20 g high quality protein consumed in a meal or snack has been demonstrated to be necessary to promote maximal rates of muscle protein synthesis (Witard *et al.*, 2014) and optimal assimilation is achieved with intake of protein containing ~10 g essential amino acids (Phillips, 2012) and a high leucine content (Murphy, Hector, & Phillips, 2015).Daily protein intake recommendations should include advice on meal planning. Intake also depends on training status, with experienced athletes requiring less (Thomas*, et al.*, 2016), meaning young less trained athletes requirements may be at the upper end of recommendations (Macnaughton *et al.*, 2016). However Mazzulla *et al.* (2018) found a recommendation of ~0.1 $g \cdot kg^{-1} \cdot h^{-1}$ during post exercise recovery or the equivalent of ~1.5 $g \cdot kg^{-1} \cdot d^{-1}$ (or ~0.3 $g \cdot kg^{-1}$ x 5 mealtimes) was sufficient to replace exercise-induced amino acid oxidative losses, enhance whole body net protein balance and support normal growth and development in a group of mix gender adolescent athletes. Protein needs in adult female intermittent team sports athletes have been calculated as 1.4 $g \cdot kg^{-1} \cdot d^{-1}$ with additional benefit from protein intakes of 0.3-0.4 $g \cdot kg^{-1}$ taken pre- and post-exercise (Mercer *et al.*, 2020).

2.5.7 Fluid recommendations for the adolescent athlete

Young male and female athletes commonly arrive at training already hypo-hydrated (Gibson, Stuart-Hill, Pethick, & Gaul, 2012; Rivera-Brown, 2016; Silva *et al.*, 2011) and adequate fluid intake during games may not compensate for poor hydration status already present ahead of training or competition (Rivera-Brown, 2016). Set guidelines requiring drinking to a plan (Kenefick, 2018) may be required for hydration in adolescent athletes, as increased knowledge

does not appear to be translated into improved hydration practices in this age group (Cleary *et al.*, 2012; Decher *et al.*, 2008). For young athletes in team sports, a good strategy is to recommend increasing fluid intakes in their daily lives, improving hydration status (Rivera-Brown, 2016) and as in adults the recommendation is to drink 5-7 $ml \cdot kg^{-1}$ fluids 4 hours before exercise (Sawka *et al.*, 2007) to ensure starting exercise euhydrated.

Adolescent athletes are regularly found to have sweat rates during exercise in excess of 1 $L \cdot h^{-1}$ and rates of 2.5 $L \cdot h^{-1}$ are not unusual in older adolescents (Bergeron, 2015), with higher rates found in competition than in training (Rivera-Brown, 2016). Sweat rates of 0.6 $L \cdot h^{-1}$ have been measured in female U21 (tier 4/5) hockey players (19.0 ± 1.0 yr) (Macleod and Sunderland, 2009). Voluntary dehydration is common during exercise in young athletes (Arnaoutis *et al.*, 2015), the variable nature of the intermittent play can make it difficult to predict sweat rates (Maughan, Shirreffs, Merson, & Horswill, 2005; Sawka*, et al.*, 2007) and within many team-sports there is often little time to drink during match play (Rivera-Brown, 2016). Macleod and Sunderland (2009) assessed fluid losses and hydration practices in elite (tier 4/5) female U21 hockey players and found no association between the amount of fluid consumed and sweat losses or pre-game urine osmolality. A wide variety of drinking practices were noted, with between 36 and 235% of sweat losses being replaced (Macleod and Sunderland, 2009). The rules of hockey allow continuous substitutions, with some players only spending short periods on the pitch and able to consume fluids regularly during the game. Macleod and Sunderland (2009) found that players who were regularly substituted consumed volumes of fluid far in-excess of their sweat losses, resulting in body mass gains. These players were also found to be more likely to have started the game euhydrated, suggesting that they may be drinking through habit.

The addition of flavouring to water has been shown to increase voluntary drinking in young male athletes and improve hydration practices (Wilk and Bar-Or, 1996) but the effect is not found in young female athletes (Rivera-Brown, Ramírez-Marrero, Wilk, & Bar-Or, 2008).

Sodas, fruit juices and energy drinks are not recommended during exercise because of their high sugar content and carbonation slowing release of fluids from the stomach, causing risk for gastrointestinal distress and interfering with proper hydration (Rivera-Brown, 2016). Sugar sweetened beverages including sports drinks account for 30% of total free sugar intake in UK adolescents (11-18 yr) (Fairchild, Broughton, & Morgan, 2017) and higher intake of sports drinks is seen in adolescents who do higher levels of MVPA (Larson, Dewolfe, Story, & Neumark-Sztainer, 2014).

2.6 Summary

The hypothesis for this thesis is that the female adolescent hockey player population are fitter, with higher energy expenditure and physical activity levels than population normative data, that the nutritional demands of playing competitive hockey are high and that adolescent girls are not adequately compensating for this with their current dietary intake. This review of the literature shows that there are currently many gaps in the published research. It is unclear whether developmental age is an indicator of hockey performance during adolescence, whether developmentally early or late maturers are being selected and whether this should be considered when looking at training load and dietary provision during exercise. Previous studies in male adolescent football have suggested that RMR and PAL are higher than estimated by existing predictive equations or tables and that dietary intake is often insufficient in this group. Adequate EA is vital during growth and development making it important to understand the demands of both training and competition. Adolescence is a key time where behaviour is changing, and individuals begin to have more autonomy over what they do and eat. Ensuring that young female hockey players have sufficient knowledge to fuel all their activity, including both the organised sport they do, and their general activity is key for their ongoing health and wellbeing as well as hockey performance.

3. STUDY 1: The Influence of Maturity Status on Physical Performance Measures in Female Adolescent Hockey Players.

3.1 Abstract

The aim of this study was to document physical performance characteristics of female adolescent hockey players at the start of the national selection pathway and make comparison with measures of maturity and body composition. **Methods**: 24 female adolescent hockey players (age 13.4 ± 0.8 yr) participated in the study. Height (162 ± 0.8 cm), seated height and body mass (53.8 ± 7.4 kg) were used to estimate maturity offset from chronological age and body composition using validated equations. Physical performance was quantified using; countermovement jump, hand grip, SlalomSDT and multistage fitness test (MSFT). **Results**: Using both the Mirwald and Moore equations all but one participant was classified as average maturing. Compared to chronological age, both measures of developmental age demonstrated stronger correlations with leg length ($r=0.52/0.69$, $p<0.01/0.001$ vs $r=0.38$ $p=0.07$) and physical performance measures of grip strength ($r=0.67/r=0.64$, $p<0.001$ vs. $r=0.58$, $p=0.003$), peak leg power output ($r=0.77/0.44$, $p<0.001$) and dribble speed ($r=0.44/0.44$, $p=0.03$ vs. $r=0.35$, $p=0.09$). Sprint speed was correlated with jump height ($r=0.53$, $p=0.008$). All other correlations were non-significant. **Conclusion**: This is the first study to describe physical performance in female adolescent hockey players and provides normative and comparative data to inform coaching and training strategies. Body stature and physical performance were above the population mean for similar aged females, in line with junior athletes and below adult female hockey players.

3.2 Introduction

Hockey is a high-intensity game with higher recorded meter per minute distances than other comparable team sports (Mcmahon and Kennedy, 2019) and high recorded heart rates for intensity of play (Mcguinness, Malone, Hughes*, et al.*, 2017). Match play is characterised by intermittent sprinting, frequent changes of direction, hitting and dribbling the ball, jumping and diving which collectively classify hockey as a 'high intensity exercise' (Mcguinness, Malone, Petrakos, & Collins, 2017) and the semi-crouched posture adopted by players further increases energy demands (Elferink-Gemser*, et al.*, 2004). Developing these skills places a significant emphasis on the muscular strength and endurance components of young developing players fitness (Elferink-Gemser*, et al.*, 2007).

Adolescent athletes are generally grouped by chronological age for the purpose of competition and training but individuals of the same chronological age vary markedly in terms of development and maturation (Baxter-Jones *et al.*, 2020). Boys who mature earlier than their peers are generally taller and heavier, and outperform later developing individuals on tests of absolute strength, power, speed and agility (Malina, Rogol, Cumming, E Silva, & Figueiredo, 2015). However, only negligible differences in physical performance (Baxter-Jones*, et al.*, 2020; Malina*, et al.*, 2004) and selection (Baxter-Jones*, et al.*, 2020) have been identified in girls with earlier development. Differences in exercise performance are often accounted for by differences in fat mass but there is a lack of comparative data available.

The physical attributes of adolescent hockey players have not previously been documented however the passages of play in hockey are closely related to those in football (Aziz*, et al.*, 2000) and the physical characteristics of adolescent football players can provide a useful reference point. In football, adolescent players anaerobic power and

capacity have been identified as major factors in the selection of players (Cunha *et al.*, 2017). Maximal strength and anaerobic power, especially in the lower limbs are important for football skills such as tackling, dribbling, jumping, sprinting, and accelerating (Wisløff, Castagna, Helgerud, Jones, & Hoff, 2004). In talented young male footballers strength, power (Granados*, et al.*, 2008) and speed (Nikolaidis*, et al.*, 2016) have been shown to be closely related to body composition, and body fat differences have been correlated (β=-0.2, $p<0.05$) with the key differences between adolescent male and female footballers in lower limb power (Gradidge and Constantinou, 2017). Lower body muscular strength is predictive of power and speed performance in college team sports (Peterson, Alvar, & Rhea, 2006) and of playing potential in Ice-hockey (Burr, Jamnik, Dogra, & Gledhill, 2007). Anaerobic leg power output has been successful in discriminating between elite (tier 3/4) (825 ± 104 w) and non-elite (tier 1/2) adult female hockey players (731 ± 94 w) (Reilly and Bretherton, 1986). Hand grip strength has been related to overall body strength in field sport athletes (Cronin, Lawton, Harris, Kilding, & Mcmaster, 2017) and identified as a measure of both overall fitness (Matsudo*, et al.*, 2014) and physical ability in developing young athletes (James, Thake, & Birch, 2017). Young female athletes are generally leaner and have lower BF% than non-athletic girls of the same age (13 yr BF% = 19% 50th centile athletic (non-aesthetic sports) vs BF% = 24% general population) (Kalnina *et al.*, 2015; Mccarthy, Cole, Fry, Jebb, & Prentice, 2006) and the difference between athletic and non-athletic girls increases through adolescence, relative fatness in non-athletes increasing with maturity whereas athletic females relative fatness is stable (Baxter-Jones and Mundt, 2007). Elite female athletes in running sports have been shown to have lower mass for stature than average, with longer legs, lower hip-to-shoulder ratios and lower fat mass (Mcmanus and Armstrong, 2011). Elite (tier 4/5) adult female hockey players have been documented to have BF% of 14-25% (Calo*, et al.*, 2009; Lemos *et al.*, 2017; Naicker, 2014) and young elite (tier 3/4) female players 10-24% (Fedotova, 2001; Georgieva*, et al.*, 2015; Krzykala*, et al.*, 2016). The average adolescent girl at the end of puberty has a BF% of 26-31% (Sherar*,*

et al., 2007). Elferink-Gemser*, et al.* (2007) measured BF% in a group of elite (tier 3/4) and sub-elite (tier 2/3) Dutch female adolescent hockey players (average age 13.9 ± 1.3) as 18.8 ± 6.1% and 22.9 ± 7.1% respectively. There has been no research published on body composition in adolescent hockey players in the UK and research on ability and skills of adolescent female hockey players or female adolescent athletes is limited.

The aims of the present study are to (1) investigate the importance of developmental age when assessing physical performance in this age group (2) quantify the physical characteristics and skill levels of adolescent female hockey players in the early stages of the national selection pathway, and how they relate to growth and maturity, and (3) compare physical characteristics and performance to normative data for the general population and elite adolescent and adult hockey players.

3.3 Methods

Participants completed a single testing session at the end of the 2015 hockey season. All testing sessions were carried out at 10 am (ambient temperature 19.7 ± 1.5 °C, humidity 37.9 ± 0.75%), on a smooth basketball court surface like that used for indoor hockey. Participants wore trainers and their normal hockey training kit. Twenty-four female participants volunteered to participate in this study. All participants were registered in England Hockey's Single system and were training at an U13-U15 County Junior Development Centre (JDC) or higher but were not specialised only to this sport. All participants were informed in advance of the procedures involved in the testing program and after receiving a written description of the study requirements, were offered an opportunity to ask questions. Participants gave assent and parents or guardians of the players provided written informed consent. Ethics approval was granted by the University of Chichester Ethics Committee.

All participants were advised that on the day of testing they should eat a normal breakfast before attending and refrain from additional exercise. All participants were reminded that they were permitted to withdraw from the study at any time with no reason needing to be given. A short warm up session lasting approximately ten minutes was conducted before testing. This was a shortened version of the RAMP (Raise, Activate, Mobilise, Potentiate) protocol consisting of a three-minute slow running drill with changes of direction, two minutes of walking lunges, two minutes doing unilateral and bilateral jumps and three minutes of stretching.

Standing and seated height were measured to the nearest 0.01 m in accordance with ISAK guidance and using a Harpenden G133 Portable stadiometer (Holtain ltd, Dyfed, UK). Body mass was measured to the nearest 0.1 kg using a Mettler Toledo PB3001-s Scales (Fisher Scientific, UK) wearing light clothing and no trainers. These anthropometric measurements were used to calculate a gauge of developmental age or maturity offset from chronological age in equations developed by Mirwald*, et al.* (2002) and Moore*, et al.* (2015). Predicted APHV was calculated as chronological age minus maturity offset. Each player was then classified as early, average, or late maturing, based on predicted APHV, following the method outlined by Sherar, Mirwald, Baxter-Jones, & Thomis (2005). Players whose predicted APHV was between 10.9 and 12.9 yr were classified as average maturing in-line with previous longitudinal growth data (Kozieł and Malina, 2018). Participants Body Mass Index (BMI) was calculated and used to estimate participants percentage body fat using the equations developed by (Jackson*, et al.*, 2002). The Jackson Equation has been found to give an accurate measure of BF% in young populations (Mittal*, et al.*, 2011) and is shown to have a lower risk of measurement error than using skin-folds (Nickerson*, et al.*, 2018) but it has not been commonly used in athletes.

Maximal isometric handgrip strength was measured in kilograms with an adjustable handgrip dynamometer (TKK 5401 GRIPD, Cranlea & Co. Birmingham, UK). Participants were given opportunity to adjust the handle to the setting they found most comfortable and were instructed to hold the dynamometer in their dominant hand, with their arm at their side. On a signal, participants were instructed to squeeze the handle as hard as possible for 5 seconds without moving their arm. At the end of 5 seconds, the score was recorded. The test was repeated 5 times with a thirty second timed recovery between tests.

To measure maximal jump height, participants were instructed to stand on a timing mat (University of Chichester, Chichester, UK) with their hands on their hips and their knees bent at approximately 90 degrees. Once in a crouched position, participants were instructed that on a signal to jump as high as they could without moving their arms and landing with their legs extended. The time in the air was recorded. Each participant completed 3 best effort jumps with a 30 second recovery between jumps. The jump height and peak anaerobic power output were calculated using the equations proposed by Bosco, Luhtanen, & Komi (1983) and Sayers, Harackiewicz, Harman, Frykman, & Rosenstein (1999).

A SlalomSDT proposed by Lemmink*, et al.* (2004) was used as sport-specific test of agility and dribbling skills. Participants were asked to complete a 30-m slalom sprint carrying a hockey stick and to then repeat the trial while dribbling a hockey ball. In both instances, it was ensured that both of the player's feet went around the outside of the mark cones. If the participant lost the control of the ball, then the dribble run was repeated immediately. Time was measured at the nearest 0.01 seconds. The test was conducted three times with a three-minute rest period between runs. The Slalom sprint, slalom dribble and the difference between the dribble and sprint times (ΔST) were recorded for each player. The ΔST was used as an index of player skill (Lemmink*, et al.*, 2004).

The Multi-stage fitness test (MSFT) used was a modified shuttle run consisting of repeated 20 m runs at an increasing pace, starting at a speed of 2.5 $m \cdot s^{-1}$ (8.0 $km \cdot h^{-1}$) (Wilkinson*, et al.*, 1999). The frequency of the audio signals used resulted in running speed increasing by approximately 0.5 $km \cdot h^{-1}$ for each stage. The test ended when the participant could no longer keep pace with the bleeps (i.e., failed to meet the 20 m line on two consecutive occasions) or retired voluntarily. The level and shuttle reached was recorded as the individuals score and peak shuttle speed was calculated. The maximal multi-stage fitness test (MSFT) has been confirmed as a valid way in which to predict VO_{2max} and a useful alternative to using a laboratory-based test in children (Mayorga-Vega, Aguilar-Soto, & Viciana, 2015).

Data was collected from 24 adolescent female hockey players and was analysed using JASP (2020), version 0.13.1. Data was checked for skewness and kurtosis and found to be normally distributed. A Pearson Correlation was used to examine the strength of the linear relationship between variables of age, developmental age, BF% and height, and the measures of hand grip strength, leg power, slalom sprint and dribble speeds and the results from the MSFT. Dependent variables were calculated and described as mean and standard deviation. In accordance with Cohen (1988) a correlation of >0.5 was classified as large, 0.5-0.3 as moderate. 0.3-0.1 small and anything smaller than 0.1 as insubstantial.

3.4 Results

Table 3.1 presents the anthropometric and physiological characteristics of the participants and Table 3.2 presents the Pearson correlation values between these measures.

The results in Table 3.2 show that all measures of strength, speed and skill improved with both age and maturity, with strong correlations between chronological age, height, and time from peak height velocity (TPHV) and hand grip and leg power measures.

All developmental age values calculated using the Moore Equation were closer to individual PHV than those calculated using the Mirwald Equation, but the values were highly correlated ($r=0.97$, $p<0.001$).

Table 3.1 Anthropometric and physiological characteristics of female adolescent hockey players. Data expressed as mean ± standard deviation and as a range of values.

ANTHROPOMETRIC AND PHYSIOLOGICAL CHARACTERISTICS	Mean	Standard deviation	Range
Height (cm)	162.0	±8	152 – 176
Leg Length (cm)	79.5	±6.1	69 – 89.5
Body Mass (kg)	53.8	±7.4	44.5 – 68.9
Estimated BF%	21	±3	16.2 - 26.7
Chronological age (yr)	13.4	±0.8	11.4 – 14.8
Age at Peak Height Velocity (Mirwald) (yr)	12.0	±0.4	11.0 – 13.0
Age at Peak Height Velocity (Moore) (yr)	11.9	±0.4	11.3 – 12.6
Maximum grip strength (kg) (dominant hand)	25.4	±5.1	17.5 – 32.9
Mean Jump Height (cm)	26.9	±3.6	20.6 - 35.8
Peak Anaerobic Power Output (legs) (W)	2014	±414	1262 – 2807
Median slalom sprint speed ($m \cdot s^{-1}$)	1.3	±0.1	1.1 - 1.6
Median slalom sprint speed ($km \cdot h^{-1}$)	4.7	±0.4	4.0 – 5.8
Median slalom dribble speed ($m \cdot s^{-1}$)	1.6	±0.2	1.3-2.1
Delta slalom time (s)	5.6	±2.3	2.0 – 12.8
Multistage Fitness Test Level	8.7	±1.5	5.4 – 11.4
Multistage Fitness Test #runs	68.5	±16.1	36 - 96
Multistage Fitness Test Speed ($m \cdot s^{-1}$)	3.4	±0.2	3.0 - 3.8
Multistage Fitness Test Speed ($km \cdot h^{-1}$)	12.4	±0.8	10.7 – 13.7
Peak Heart Rate (BPM)	204	±10	187 - 224
VO2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	42.7	±4.6	33.4 – 50.4

Table 3.2 Association between growth or maturity and physical performance measures in female adolescent hockey players. Relationship expressed as Pearson Correlation (2tailed) and p value. * p < .05, ** p < .01, *** p < .001

		Grip Strength	Peak Anaerobic Leg Power	Slalom Sprint speed	Dribble speed	Sprint/ Dribble (Delta sprint /dribble)	Heart Rate	MSFT	VO2Max
BF%	r	0.35	0.49	0.06	-0.24	-0.37	-0.20	-0.38	-0.41*
	p	0.10	0.015	0.80	0.26	0.07	0.34	0.65	0.05
Height	r	0.56**	0.67**	-0.48*	-0.43*	-0.18	-0.30	0.11	0.11
	p	0.005	<0.001	0.02	0.04	0.40	0.15	0.60	0.62
Leg Length	r	0.37	0.5*	-0.41*	-0.36	-0.14	-0.17	0.33	0.32
	p	0.08	0.013	0.04	0.09	0.51	0.42	0.12	0.13
Grip Strength	r		0.81***	-0.49*	0.69***	-0.51*	-0.05	0.17	0.44
	p		<0.001	0.016	<0.001	0.01	0.83	0.42	0.17
Chronological Age	r	0.58**	0.64***	-0.14	-0.36	-0.36	-0.20	0.04	0.06
	p	0.003	<0.001	0.50	0.09	0.09	0.35	0.85	0.93
TPHV Mirwald	r	0.67***	0.77***	-0.33	-0.44*	-0.32	-0.32	-0.04	-0.06
	p	<0.001	<0.001	0.11	0.03	0.13	0.13	0.84	0.79
TPHV Moore	r	0.64***	0.74***	-0.33	-0.44*	-0.32	-0.28	0.08	-0.06
	p	<0.001	<0.001	0.12	0.03	0.12	0.18	0.72	0.77

3.5 Discussion

This is the first study to describe the anthropometric and physiological characteristics of female adolescent hockey players playing in the early stages of England Hockey's Single

System and to investigate associations between chronological and developmental age with performance measures of strength, speed, fitness, or skill.

Due to the association with hormonal and muscular changes during puberty, it was hypothesised that both growth and performance measures would be more closely linked with somatic maturity or TPHV than with chronological age. The results of the present study show larger r values for TPHV than chronological age for grip strength, anaerobic leg power output and slalom dribble but the difference was small.

The anthropometric characteristics of the participants in the present study were in line with studies in both female adolescent athletes and non-athletes. The average APHV in the present study was 12 ± 0.4 yr calculated by the Mirwald Equation (Mirwald*, et al.*, 2002) and 11.9 ± 0.4 yr calculated by the Moore Equation (Moore*, et al.*, 2015) and all but one participant was classified as average maturing. In a review of research measuring the PHV of female non-athletes, Malina*, et al.* (2004) showed that in Europe female adolescent's APHV was most commonly found to be between 10.7 and 13.4 yr. There has been limited research in athletes but studies in female rowers (APHV = 12.0 ± 0.9), gymnasts (APHV = 12.9 ± 1.8), track and field athletes (12.1 ± 0.8) and mixed athletes (12.3 ± 0.8) suggest there is little variation between athletes and non-athletes, and that the participants in this study fit into the wider population (Malina*, et al.*, 2015). Previous research has found female athletes are more likely to be average or late maturing (Malina*, et al.*, 2015).

The average non-athlete adolescent girl of European ethnicity has been identified as having a BF% at the end of puberty of 26-31% (Sherar*, et al.*, 2007). Elferink-Gemser*, et al.* (2007) measured BF% in a group of elite (tier 3/4) and sub-elite (tier 2/3) female adolescent hockey players (age 13.9 ± 1.3 yr) finding the elite players had a BF% of 18.8 ± 6.1% and the sub-elite players of 22.9 ± 7.1%. The BF% of the participants in present study, 21.4 ± 3.2%, is between these elite and sub-elite players and below the normative

data for girls of European ethnicity. Elite (tier 3/4) Russian (Fedotova, 2001) and Bulgarian (Georgieva*, et al.*, 2015) female adolescent hockey players have been recorded as having considerably lower BF% of between 10 and 14% and BF% in elite (tier 4/5) adult female hockey players have also been reported as low as 14% (Naicker, 2014). The present study did not examine playing position and playing position was not referred to in any of the adolescent studies (Elferink-Gemser*, et al.*, 2007; Elferink-Gemser*, et al.*, 2004; Fedotova, 2001; Georgieva*, et al.*, 2015), however Calo*, et al.* (2009) did identify significant differences in body composition between different outfield playing positions in adult female players. An uneven distribution of a single playing position in the participant group in any of these studies may have distorted the average body fat percentage reported. Playing position was not recorded in the present study as the participants had identified that they can play a variety of positions during games.

Muscular strength, power and speed are important determinants of performance in intermittent team sports during adolescence (Burr*, et al.*, 2007; Peterson*, et al.*, 2006; Wisløff*, et al.*, 2004). In hockey, grip strength is important for controlling the stick during the execution of key skills, and upper body strength allows players to shoot more powerfully, and tackle and pass over a range of distances. In the present study, as shown in Table 3.2, maximum hand grip strength (kg) and peak anaerobic leg power (W) were both correlated to chronological age and strongly correlated to the TPHV calculated using both the Mirwald and Moore Equations. TPHV was also associated with the speed at which the ball was dribbled down a 15 m slalom course. Increased strength during adolescence has been shown to result in improved jump, sprint and Wingate test performance and be directly related to increased leg length and muscle size with maturity, in male adolescent footballers (Moran, Sandercock, Ramirez-Campillo*, et al.*, 2017).

Handgrip is the most regularly used test for strength in hockey players. Elite (tier 3/4) and sub-elite (tier 1/2) adult players have grip strengths of between 32 kg and 36 kg (Keogh*, et al.*, 2003; Ucan, 2015). Very little data is available on female adolescent hockey players but Fedotova (2001) recorded maximum hand grip strength in Russian elite (tier 3/4) female players at a specialist sports school as 26.5 ± 6.5 kg at age 12 yr, 29.7 ± 6.4 kg at 13 yr and 34.7 ± 6.1 kg at 14 yr. These observations are higher than found in the present study. Female athletes are known to be significantly stronger than their untrained female counterparts with hand-grip strength linearly correlated with lean body mass (Leyk*, et al.*, 2007), which may explain this difference. Although the participants in the present study were playing hockey competitively, they were not doing the hours of specialised training that would be associated with an elite (tier 4) player. Using the framework outlined in (Mckay*, et al.*, 2022) participants in the present study would predominantly be classed within tier 2 or 3, whereas the 'well-trained' players in Fedotova (2001) who trained 12 months a year and were pupils at special sports school within the Olympic Reserve in Moscow would be classified within tier 3/4.

Hand grip strength in the present study was strongly correlated with leg strength ($r=0.81$, $p<0.001$). Other studies in children and adolescents have reported a similar relationship linking increased performance with chronological age and muscle development both in the general population (Fricke and Schoenau, 2005) and elite (tier 4) female footballers (Vescovi, Rupf, Brown, & Marques, 2011). In the present study, as shown in Table 3.2, leg power was also associated with BF%. Differences in lower-limb power performance between developing male and female football players has been directly linked to differences in body composition (Gradidge and Constantinou, 2017) and Lemos*, et al.* (2017) investigating the links between anthropometric parameters and performance in female Brazilian adult hockey players concluded that BF% was the only measure that predicted hockey specific performance. This was not shown in the present study,

calculated BF% not being significantly correlated with developmental age, sprint agility or dribble speeds.

Mean jump height in the present study was 26.9 ± 3.6 cm, which places the group at the 50th percentile of jump height for age, when compared to normative data for female English school children (Taylor*, et al.*, 2010). Peak anaerobic leg power output, calculated taking mass into account was 2014 ± 414 W and between the 50th and 75th percentile of leg power compared to normative data in similar aged girls (Taylor*, et al.*, 2010). No previous research has recorded countermovement jump heights or leg power output in female adolescent hockey players but a review of football studies from 1995-2010 reported a mean jump height for under 18 girls of 27.9 ± 3.1 cm (Haugen*, et al.*, 2012) and Datson (2016) documented the jump height in two studies in 15 yr old elite (tier 4) female players as 26.6 ± 3.7 cm and 26.4 ± 3.4 cm, both of which are comparable with the adolescent athletes in the present study (26.9 ± 3.4 cm). Although it has not been studied in female players, no significant difference was found between jump performance measures in male hockey and male football players (Singh*, et al.*, 2016) making this a good comparison.

The female adolescent hockey players in the present study had a mean slalom sprint speed without the ball, of 16.3 ± 2.2 s. Elferink-Gemser*, et al.* (2007) measured female elite (tier 3/4) and sub-elite (tier 2/3) Dutch adolescent players (13.9 ± 1.4 yr) with speeds of 15.2 ± 0.9 s and 15.4 ± 1.2 s respectively, faster than found in the current study. However, when dribbling the ball, the Dutch adolescents had mean peak times of 19.7 ± 1.8 s (elite) and 20.1 ± 2.7 s (sub-elite), very similar to the mean dribble speed of 19.9 ± 3.5 seconds in the present study. In the Dutch studies the biggest difference between the elite and sub-elite performances was in the slalom dribble times (Elferink-Gemser*, et al.*, 2007; Elferink-Gemser*, et al.*, 2004) and better adult female hockey players have also demonstrated higher running speed while dribbling the ball than lower league players (Reilly and Bretherton, 1986). In hockey, it is important that players are quick

and agile with and without the ball, being in contact with or dribbling the ball for between 17.5 – 30.0% of match-time (Lothian and Farrell, 1994). The comparatively good performance of the participants in the present study would identify them as a group with above average skill.

As shown in Table 3.2 SlalomSDT speeds in this study and were found to improve with height. Care was taken to ensure that participants were moving their feet around the course, but this could suggest that there may have been an advantage for taller participants with greater reach. There was no association between either sprint or dribble times and chronological age but a small positive association between TPHV and higher dribble speeds ($r=-0.44$ $p=0.033$). Sprint and dribble were negatively associated with increased grip strength and leg power and this association was strongest for the slalom dribble ($r=-0.7$ & $r=0.7$, $p<0.001$). As in adult studies where the best female hockey players have been identified as the ones who can move most explosively over the two 35 minute halves (Anders and Myers, 2008), with frequent high intensity bursts of activity and rapid acceleration, deceleration and turning, all requiring explosive power output from the legs (Burr*, et al.*, 2007) the stronger participants in this study demonstrated stronger results across all measures.

Aerobic fitness has been identified as a key factor in determining team sport performance. In the present study, aerobic fitness was measured using a modified 20 m MSFT (Wilkinson*, et al.*, 1999). Comparison of this data with a systematic review of studies in children and adolescents since 1981, showed the participants in the present study performed above the 95 centile of the general population on MSFT score and closer to the performance of similar aged boys (Tomkinson*, et al.*, 2017). The mean running speed represented by the last stage completed was 3.4 ± 0.2 $m \cdot s^{-1}$, significantly higher than international normative data for this age group, where the 95^{th} percentile for 13 yr. old girls is 3.1 $m \cdot s^{-1}$ and 14 yr. old girls is 3.2 $m \cdot s^{-1}$ (Tomkinson*, et al.*, 2017). All the participants in the present study were very familiar with the test and there was

considerable competition between individuals, which may have contributed to these observations. The MSFT results were used to calculate participants VO_{2max} giving a mean VO_{2max} of 42.7± 4.6 $mL \cdot kg^{-1} \cdot min^{-1}$. Normative data exists for adolescents within the general population for English school children (Sandercock*, et al.*, 2012) and European children and adolescents (Moran, Sandercock, Ramirez-Campillo*, et al.*, 2017) and the American College of Sports Medicine (ACSM) provide suggested categories of VO_{2max} performance for each age group. ACSM data indicates that a VO_{2max} of 35.0–38.9 $mL \cdot kg^{-1} \cdot min^{-1}$ would be categorised as good, 39.0-41.9 $mL \cdot kg^{-1} \cdot min^{-1}$ as excellent and >41.9 as superior (Liguori, 2021). On this scale, 75% of the participants within this study would have VO_{2Max} classed as excellent and all but one would be either good, excellent, or superior. Similarly high values (40.6 ± 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$) were found in the only published study in female adolescent hockey players (tier 3/4) (15.9 ± 2.2 yr) (Pal*, et al.*, 2017). Very high, superior VO_{2max} levels have been found in female adolescent netball players (14.1 ± 0.8 yr, 44.5 ± 3.6 $mL \cdot kg^{-1} \cdot min^{-1}$) (Rumbold, 2011) and in adolescent female runners (16.0 ± 0.8 yr, 48.0 - 63.2 $mL \cdot kg^{-1} \cdot min^{-1}$) (Fernhall*, et al.*, 1996) both calculated from MSFT. Adult hockey players have a range of VO_{2max} values of 43.9 - 59.03 $mL \cdot kg^{-1} \cdot min^{-1}$ in treadmill tests and 42.87 ± 9.08 $mL \cdot kg^{-1} \cdot min^{-1}$ from bench stepping (Astorino*, et al.*, 2004).

Developmental age, measured by the time from peak height velocity was expected to have a greater relationship with performance measures than chronological age but although stronger correlations were seen, the difference was small. In a larger sample greater difference may have been seen, especially as the participants in this study were all classified as average maturers, with a tight distribution of APHV. Both sets of equations for assessing peak hight velocity gave equivalent results. The Mirwald Equation has been commonly used in studies, giving greater comparative data but the more recently developed Moore Equation, using only one measure of height, may be

easier for use in the field. Use of the Jackson Equation to calculate BF% worked well as a non-invasive way to assess BF% in this vulnerable group.

In conclusion, the present study is the first to describe the physical ability and skill level of adolescent female hockey players using recognised sprint, strength, and dribble tests, and to document the relationship with measures of growth and maturity. The results show there to be no identifiably stronger relationship between developmental age and the physiological tests used than with chronological age. All the tests showed that all the measurements were in line with similar studies of active adolescents or elite/sub-elite female adolescent team sport players, suggesting that this group of participants was similar to other adolescent athletes in most measures. The measures of strength, particularly hand grip, were lower than seen in similar aged elite (tier 3/4) international hockey players but above population averages, these differences may reflect a difference in training, as none of the participants in this study were doing sport specific strength and conditioning. The IOC consensus statement on training the elite child athlete defines a child athlete as “one who has superior athletic talent, undergoes specialist training, receives expert coaching and is exposed to early competition” (Mountjoy*, et al.*, 2008). From the findings in Study 1, it is judged that this group of female adolescent hockey players could be defined as athletes, and so likely to benefit from specialist nutrition support.

To further develop an evidence-base to inform a nutrition intervention designed to maximise health and performance in this group it is important to assess the level and type of training and hockey match-play that is being done. The match and training demands, heart rate and metabolic power characteristics of female adolescent hockey players have not been studied before and are assessed in Study 2 and 5 of this thesis, and the impact of training volume and the number of sports played is addressed in Study 4. Research in adolescent male athletes has identified a strong relative age effect by which developmentally older individuals have a selection advantage (Cumming, Lloyd,

Oliver, Eisenmann, & Malina, 2017; Malina*, et al.*, 2004). There was no evidence of selection bias within this group of adolescent hockey players who had been put forward to Junior Development Centres, with all but one being average developers and there was no identified link between developmental age and performance.

4. STUDY 2: Physical Performance, Heart Rate and Metabolic Power Characteristics of Female Adolescent Hockey Players in an U16 League Match.

4.1 Abstract

The purpose of this study was to examine physical performance characteristics and EE of female adolescent hockey players during match-play and compare these to the adult game. **Methods**: Forty-five female adolescent hockey players (mean age 13.8 ± 1.82 yr; stature 163.7 ± 7.8 cm; body mass 53.2 ± 8.1 kg) were fitted with heart rate monitors (Polar H10, Polar Electro UK Ltd, Warwick UK) and GPS device (Catapult OptimEye s5, Catapult Innovations, Melbourne, Australia), during four U16 League Games, Distance travelled, match intensity in six speed zones, peak velocity, heart rate and metabolic power were measured to assess physical performance and EE. Three factor ANOVAs compared each dependent variable for match position and paired t-tests were used to compare measures in the first and second half. **Results**: Pitch time was 49.3 ± 12.1 mins, (~70% of full match time) with no difference between playing positions ($p=0.74$). Mean distance covered was 4,175 ± 1,473 m and 79% of pitch time was recorded to be in low intensity velocity bands (50 ± 10% standing, 28 ± 6% walking). Forwards had greater max velocity than midfield players or defensive players ($p<0.005$, $p<0.001$). EE estimated from metabolic power was 8.0 ± 2.0 $kcal \cdot kg^{-1}$, 452 kcal for the game. **Conclusion**: This is the first study to describe physical performance in female adolescent hockey players and provides normative and comparative data to inform coaching, training, and nutritional strategies. Although distances covered and the structure of play in adolescent hockey is similar to female adult and elite hockey, the intensity of play is lower, and there is less positional difference both in tactical substitution and player movement velocity.

4.2 Introduction

To assess the physiological demands and nutritional requirements for female adolescent hockey players it is important to understand the physical activity and EE profile of playing competitive hockey at this age. The use of GPS provides a non-evasive, time-efficient, and accurate approach to describe and analyse the physiological demands of sport (Aughey, 2011; Cummins*, et al.*, 2013; Edgecomb and Norton, 2006; Macleod*, et al.*, 2009; Townshend*, et al.*, 2008). The use of GPS is common in male and female adult hockey to study components of match demands and training load (Gabbett, 2010; White and Macfarlane, 2015a), however no such research has been conducted in female adolescent hockey players.

Hockey games are intermittent, with prolonged periods of moderate to low intensity activity randomly interspersed with brief periods of high to maximal intensity work (Bishop and Claudius, 2005). The International Hockey Federation review the rules of hockey every two years; changes in the past three decades include the introduction of rolling substitutions (1992), the introduction of the self-pass rule (2009), the introduction of stopped time for penalties or injuries (2014) and a move to play International and National League games as four 15-minute quarters (between 2014 & the formal rule change in 2018/2019). Abbott (2016) and Mcguinness*, et al.* (2020) have quantified the physiological demands and movement patterns in the female adult game before and after the move to quarters (2014-2019) and both concluded that these changes have significantly impacted match intensity, shifting the emphasis from endurance to speed and agility. Recommendations have been made for young athletes playing in age group development squads to emulate this shift in performance characteristics (Vescovi, 2016).

Most studies using GPS during match play report the distance covered by players to quantify players physical activity. The distance is then divided by pitch-time to calculate relative distance ($m.min^{-1}$) and categorised into PA zones by velocity; the time spent

standing, walking, jogging, running, and sprinting. Published distances covered by elite (tier 4/5) adult female players over a 70 minute match has been reported as ranging from 2,300 m (Abbott, 2016) to 6,900 m (Gabbett, 2010). However, no indication of individual pitch-time (i.e., total amount of time on the pitch during the 70-minute game) was provided by Gabbett (2010) and although the average pitch-time was provided by Abbott (2016) as 41 mins, players with the lowest recorded distances averaged a pitch time of just 19 mins, less than a third of playing time. Studies in female US College Players (Vescovi and Frayne, 2015) and UK University Teams (Leslie*, et al.*, 2008) show higher distances travelled (6,062 ± 1,371 and 7,230 ± 147 respectively) but also higher times on the pitch (74 ± 3 & 57 ± 13 mins). In adult male players (25 ± 4 yr) the distance travelled has been found to be unrelated to the time spent on the pitch (White and Macfarlane, 2013) but this has not been confirmed in the women's game.

For female hockey players, relative distance or total distance travelled per minute of competition game time ($m \cdot min^{-1}$) may provide a more accurate reflection of match intensity than total distance covered, taking an individual player's time on the pitch into account. Relative distance in $m \cdot min^{-1}$ is now a commonly used measure in team sport analysis, where player substitution gives uneven playing times and it is also valuable when comparing junior and senior games (Beenham*, et al.*, 2017; Cunningham*, et al.*, 2016; Henderson*, et al.*, 2015; Torres-Unda*, et al.*, 2016). This measure is particularly important in youth hockey where rolling substitution with squads of 16 players means the amount of time played can vary considerably between individual players, different positions, or different game formats. Match lengths often vary between club, school, national and international competitions. The effect of these differences has been studied in Football and Rugby but not hockey (Atan*, et al.*, 2014; Cunningham*, et al.*, 2016).

Analysis of the relative distance covered also allows better study of positional differences in demands of play. Adult defensive and midfield players frequently cover greater distances overall but lower distances per minute of pitch time (Abbott, 2016; Delves*, et*

al., 2019; Mcguinness*, et al.*, 2019; Mcguinness*, et al.*, 2020; Vescovi, 2016; Vescovi and Frayne, 2015; Vinson*, et al.*, 2018). It is unclear as to whether this relationship holds in junior players where positional zones of play may not be as well defined. There has been speculation that youth team sport players cover greater distances than adults due to higher work rates (Bar-Or, 1977), lower tactical awareness and poor ball control (Payne and Isaacs, 2011; Williams, 1983). However, this has not been found in male academy football players, with age being positively associated with total distance covered and distance travelled per minute, U18 players covering 27% greater distance than U13 players (8,867 m) (Buchheit*, et al.*, 2010) and U16 players covering a 10% higher relative distance than U13 players (115.2 $m \cdot min^{-1}$ vs 103.7 $m \cdot min^{-1}$) (Harley*, et al.*, 2010).

The measurement of intensity depends on the speed banding used to classify a sprint, run, jog or walk and can be difficult to interpret (Sweeting*, et al.*, 2017). Most studies have used set descriptors of the different speed bands but Vescovi (2016) in the analysis of U17 and U21 female hockey players (tier 3/4) performance and Vinson*, et al.* (2018) studying UK club players (tier 3/4) have used individualised bands. The relative merits of using individual velocity bands or generalised bands is discussed by Sweeting*, et al.* (2017) with the conclusion that practitioners should select thresholds of an equal band width and that sports should try to standardise the bands used, to allow better comparison between studies. A wide variety of velocity bands have been used for the analysis of female hockey games, with little consensus on the number of categories or band velocity (Abbott, 2016; Gabbett, 2010; Macutkiewicz and Sunderland, 2011; Vescovi, 2016; Vescovi and Frayne, 2015). Leslie (2012) proposed lower velocity bands and zones for use with junior and female hockey players and these have been adopted in recent male U18 studies (Van Der Merwe and Haggie, 2019; Wylde, 2014). The low intensity bands were designed to be comparable to previous studies but the sprint velocities were lowered to reflect the inclusion of junior players (Bradley and Vescovi,

2015; Leslie, 2012). Equivalent lower velocity bands are also used in elite (tier 4/5) female football; high-speed running being classified as >4.0 $m \cdot s^{-1}$ and sprinting >5.5 $m \cdot s^{-1}$ (Datson*, et al.*, 2017).

GPS measured velocity and acceleration can be used to derive an estimate of metabolic power and EE, using the assumption that the demands of acceleration are equivalent to the demands of running uphill at a constant speed (Di Prampero*, et al.*, 2005; Osgnach*, et al.*, 2010). This allows the cost of changing speed to be added to the demands of activity, which is important for the analysis of hockey due to the frequent changes of speed and direction. Macleod*, et al.* (2007) reported female internationals completed 960 ± 272 motion changes during games equating to an activity change every 3 s. Although GPS-derived metabolic power parameters are known to underestimate overall EE when compared to open circuit spirometry (Buchheit, Manouvrier, Cassirame, & Morin, 2015), the algorithms used have strong validity and a stronger association with EE than other available measures, such as distance travelled or player load (Highton*, et al.*, 2017). Metabolic power has been previously used to assess EE in male (Polglaze*, et al.*, 2017) and female (Vescovi and Frayne, 2015) adult hockey players. Knowing the energy demands of female adolescent hockey match play is key when formulating accurate advice for the correct fuelling strategies to ensure energy intake is adequate to cover both hockey performance and individual needs for growth, health, and training adaptation.

There are no published studies on the movement patterns and match intensity in adolescent female hockey players. The aim of this study was to examine the activity level, movement intensities and EE of players playing within an U16 league both to (1) contextualise nutritional requirements of match play and recovery to better advise players and to (2) better understand the physiological demands. Understanding the demands of play and how these compare to the adult game will inform coaching practice allowing better preparation of adolescent players for the adult game.

4.3 Methods

4.3.1 Participants

A group of 45 female adolescent hockey players (mean age 13.8 ± 1.82 yr; stature 163.7 ± 7.8 cm; body mass 53. ± 5.6 kg) were contacted via their hockey club. All the participants were either registered in England Hockey's Single system or playing at an equivalent level for their club. Ethics approval for the study was obtained from University of Chichester Research Ethics Committee. All participants were informed of the study procedures via a written and verbal description and were offered the opportunity to ask questions. The players, parents or guardians provided written informed consent. All participants were reminded that they were permitted to withdraw from the study at any time with no reason needing to be given and that their data would be deleted. Standing height was measured to the nearest 0.01 m in accordance with ISAK guidance using a Harpenden G133 Portable stadiometer (Holtain ltd, Dyfed, UK). Body mass was measured to the nearest 0.1 kg using a Mettler Toledo PB3001-s Scales (Fisher Scientific, UK).

4.3.2 Match analysis

A total of four games were analysed, specifically selected to be between teams of equivalent standard based on the results of previous games and size of club. All games consisted of two 35-minute halves and were scheduled U16 league games. All games took place outdoors on a sand-based AstroTurf hockey pitch. Although some participants played in more than one match, their data was only collected in the first game they played. Participants were divided into three positional groups – forwards (n=13), midfield players (n=18) and defenders (n=14) and wore their own standard hockey kit and footwear, shin pads and mouthguard. One hour before the start time of the match, the

participants were fitted with a heart rate monitor (Polar H10, Polar Electro UK Ltd, Warwick UK) and GPS device (Catapult OptimEye s5, Catapult Innovations, Melbourne, Australia), which sampled at 10 Hz. GPS units were placed in a small well-fitting vest top and the unit positioned between the shoulder blades. Individual players movement was tracked for the full warm up and game. The Catapult OptimEye s5 are an update of the Catapult Minimax 10Hz GPS with published validity and reliability within team sports (Johnston, Watsford, Kelly, Pine, & Spurrs, 2014; Varley, Fairweather, & Aughey1, 2012) and the use of GPS has been shown to be an effective way of assessing player movement patterns in female hockey players (Macleod*, et al.*, 2009). Playing time was calculated using the GPS and HR data and checked using a written record. Heart rate readings were collected simultaneously by the Catapult monitor. Data was downloaded onto a laptop computer and analysed using Catapult Sprint Logan software. Catapults metabolic power parameters are based on the calculations published by Minetti, Moia, Roi, Susta, & Ferretti (2002) and Osgnach*, et al.* (2010). The pitch coordinates were logged within the system and the velocity bands were set matching those used in U16 hockey players by Leslie (2012) and shown in table 4.1. Time on the substitute bench was not analysed or included in any calculations of rest or low intensity exercise.

Total distance and the distance travelled during the warm-up, first and second halves, time on the pitch, movement velocity, heart rate and power data were downloaded into excel for analysis. EE during the match (excluding the warm up) was estimated by using the accelerometer data from the GPS device to derive an EE from metabolic power using the model proposed by Di Prampero*, et al.* (2005).

Table 4.1 GPS Speed Zones ($m \cdot s^{-1}$) adapted from Leslie (2012)

Speed ($m \cdot s^{-1}$)	Description	Speed Band
0-0.83	Standing	LOW
0.86-1.67	Walking	
1.69-2.77	Jogging	MODERATE
2.80-4.02	Running	
4.05-5.28	Fast running	HIGH
>5.31	Sprinting	

4.3.3 Statistical Analysis

Data was analysed using JASP Team (2020) version 0.13.1. Dependent variables were calculated for all measures and were described as mean and standard deviation. Data was assessed for normality using histograms and Shapiro-Wilks tests and outliers checked. Time on the pitch, match distance, relative distance, speed, and the percentage of time spent in three speed zones were compared for the three on-field pitch positions (forward, midfield and defence) using Analysis of Variance (ANOVA). Paired T-tests were used to investigate the difference between match halves. Bonferroni's post hoc tests used to identify the direction of any differences. The level of significance was set at $p = 0.05$. Pearson Correlation was used to examine the strength of the linear relationship between time, distance and speed and the coefficient of determination (r^2) reported. In accordance with Cohen (1988) a correlation of >0.5 was classified as large, 0.5-0.3 as moderate. 0.3-0.1 small and anything smaller than 0.1 as insubstantial.

4.4 Results

There was no difference between playing positions on measures of age (p=1.0) and no difference in time played, distance or relative distance between the four matches played (p>0.05).

Table 4.2 shows the total time on the pitch, time played in each half of the game and the total match distance for each position grouping. The time on the pitch varied considerably between players in all positions (29 – 70 mins) and there was no difference between positions (p=0.74). Total time on the pitch was related to the total distance covered (r=0.6, p<0.001) and game distance (r=0.9, p<0.001) but there was no difference between halves for meters covered per minute (p=0.53) or mean heart rate (p=0.49) (Table 4.3).

Table 4.3 shows the match data grouped into movement zones; low intensity (standing and walking), medium intensity (jogging and running) and high intensity movement (fast running and sprinting). The percentage of time spent in each of the six velocity zones is shown in Figure 4.1. There was no difference between the positions for total distance (p=0.70) or game distance (p=0.94). Defenders completed less warm-up distance (34.6%) and spent a greater proportion of the match in low intensity activity bands (6.7%) than forwards, but the difference was not large (p=0.12, p=0.13). Forwards did a greater proportion of high-speed running (p=0.002, p=0.01) and spent more time in high intensity bands (p< 0.001, p=0.003) than defenders or midfielders respectively. Forwards also had greater max velocity $m \cdot sec^{-1}$ than defenders (p=0.002) and midfield players (p=0.01). Distance covered in the warm-up was high, with 24% of all players and 46% of forwards covering over a 1,000 m in distance and 3 forwards covering over 2,000 m. Warm up distance was positively correlated with mean HR in the first half (r=0.36 p<0.02) and negatively correlated with both time on the pitch in the second half (r=-0.42, p<0.005) and total pitch time (r=-0.36, p<0.02). The warm-up was divided into two parts, a team

warm up consisting of dynamic stretching and a ball session where the team was split by position. There was no difference between the positions on estimated EE (p=0.44).

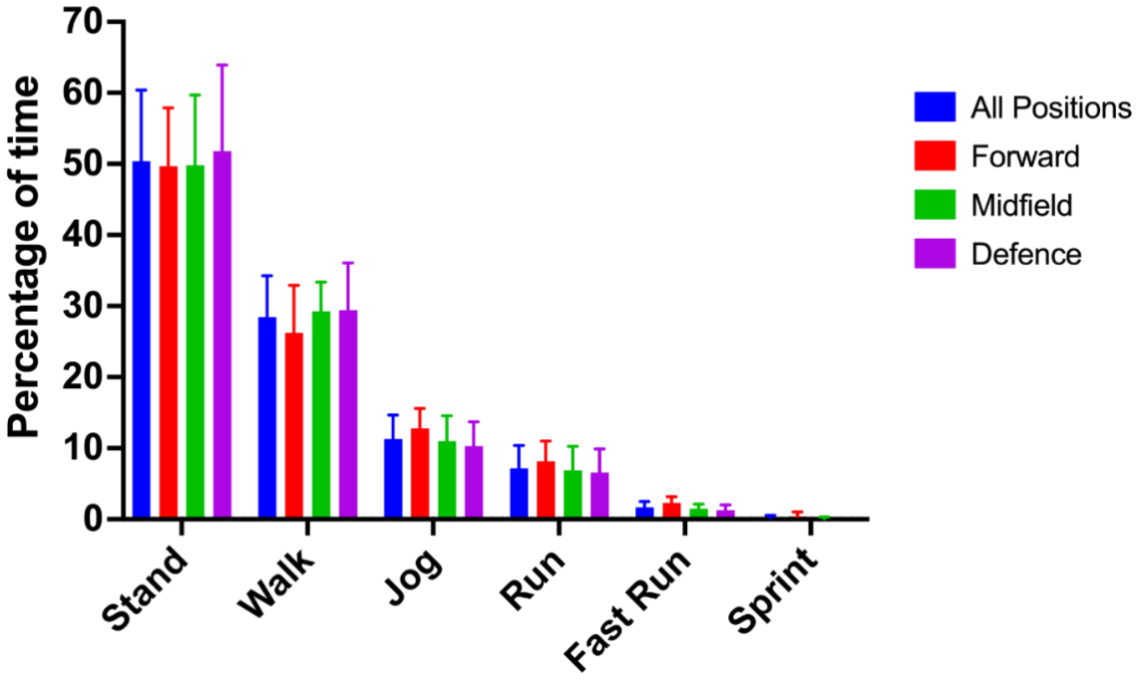
Table 4.2 Time on the pitch, distance travelled, and relative distance travelled during league matches played by female adolescent hockey players and separated by stated playing position. Data expressed as mean ± standard deviation. Difference between positions are expressed by * p<0.05, ** p<0.01, *** p<0.001, n=45.

	Total	Forward	Midfield	Defender
Total Time on pitch (min)	49.3	47.3	49.3	51.1
	±12.1	±13.2	±10.6	±13.3
Time played H1 (min)	27.3	25.5	28.6	27.2
	±6.7	±6.9	±6.6	±6.8
Time played H2 (min)	22.0	21.8	20.7	23.9
	±7.7	±7.9	±7.4	±8.2
Match distance (m)	4175	4247	4205	4069
	± 1473	±1462	±1418	±1646
H1 distance (m)	2278	2254	2367	2199
	± 782	±857	±736	±809
H2 distance (m)	1897	1994	1838	1871
	± 838	±774	±811	±920
Relative distance H1 ($m \cdot min^{-1}$)	85	86.4	84.6	81.0
	± 20	±17.5	±21.3	±21.5
Relative distance H2 ($m \cdot min^{-1}$)	85	91.7	87.4	76.3
	± 19	±13.3	±16.9	±21.2
Warm up Distance (m)	1018	1232	976	868
	± 472	±551	±477	±282

Table 4.3 Velocity and energy expenditure values for female adolescent hockey players split by stated playing position. Data expressed as mean ± standard deviation. Difference between positions are expressed by * p<0.05, ** p<0.01, *** p<0.001, n=45.

	Total	Forward	Midfield	Defender
Max velocity ($km \cdot h^{-1}$)	21.19 ±1.81	22.6**,* ±0.85	20.8* ±1.4	20.3** ±2.2
EE ($kcal \cdot kg^{-1}$)	8.0 ± 2.0	8.5 ± 1.7	8.6 ± 1.8	8.2 ± 2.5
EE ($kcal \cdot match^{-1}$)	452 ±125	436 ±113	461 ±120	456 ±148
Low intensity (stand or walk) ($\% \cdot match^{-1}$)	78.8 ± 6.9	75.9 ±4.8	79.1 ±7.2	81.2 ±7.5
Moderate intensity (Jog or run) ($\% \cdot match^{-1}$)	18.4 ± 6.2	20.9 ±4.9	17.9 ±6.6	16.9 ±6.5
High intensity (fast run or sprint) ($\% \cdot match^{-1}$)	1.8 ± 1.0	2.7***,** ±1.1	1.6** ±0.8	1.3*** ±0.7
Mean HR first half ($beats.min^{-1}$)	161 ±17	163 ±18	158 ±19	164 ±12
Mean HR second half ($beats.min^{-1}$)	163 ±14	156 ±15	167 ±12	165 ±13

Figure 4.1 Percentage of pitch time played in each velocity band; standing, walking, jogging, running, fast running, and sprinting in female adolescent hockey players split by position played. Data expressed as mean ± standard deviation.



4.5 Discussion

This is the first study to quantify the physical activity profiles and EE of match play in female adolescent hockey players. Total distance covered was 4,175 ± 1,473 m, with a relative distance of 85 ± 20 m·min^{-1}. There were no differences between the two halves played. Across all positions combined, 78.8 ± 6.9% of match play was at low intensity; either standing or walking and only 1.8 ± 1.0% of movement recorded consisted of high intensity movement; fast running or sprinting.

Average pitch time in the present study (49.3 ± 12.1 minutes; 70% of full match time) was similar to that found in studies looking at the match demands in female university and adult club hockey players (Leslie, 2012; Vescovi and Frayne, 2015; Vinson*, et al.*,

2018). However, although forwards in the present study were substituted more often than midfield or defensive players, there was no significant difference between any playing position's time on pitch, which has not been found in other studies. Macutkiewicz and Sunderland (2011) recorded UK international female hockey players (tier 4/5) spending an average of 69% of match time on pitch (48 ± 4 mins) during international games with midfield players and defenders spending significantly more time (71%, 50 ± 10 minutes and 80%, 56 ± 11 minutes) on the pitch than forwards (54%, 38 ± 7). The same relationship has been shown in International USA (tier 4/5) and Irish players (tier 4/5) with midfields averaging 69 - 76% (41.4 ± 8.3, 45.72 ± 10.1 min), defenders 82 - 95% (57.5 ± 11.4, 49.1 ± 13.5 min) and forwards just 63% of match time (38.25 ± 1.3, 40.08 ± 8.5 min) (Abbott, 2016; Mcmahon and Kennedy, 2019). Sub elite (tier 1/2/3) games do record fewer substitutions, longer pitch times and less positional difference but in all published studies, forwards are substituted more often and have less time on the pitch and this is measurable (Leslie, 2012; Vescovi and Frayne, 2015; Vinson*, et al.*, 2018). Leslie (2012) using GPS to study U16 and U18 UK Internationals (tier 4) gave a pitch time across all positions in both age groups of 46 mins (66%, U16 46.43 ± 1.5 & U18 46.26 ± 0.02 min) and Vescovi (2016) recorded pitch time for Canadian U17 Internationals (tier 4) as 39.0 ± 15.8 minutes (56%) suggesting that at the international level substitutions of all players were more frequent and that this is something that junior players should be preparing for as they move up through training groups.

Total distance covered in the present study across all positions was 4,175 ± 1,473 m, which is comparable to the distances recorded in female England International U16 (4,962 ± 295 m) (Leslie, 2012) and Canadian International U17 players (4,071 ± 1,476 m) (Vescovi, 2016) but lower than female adult International matches 5,200-12,000 m (Abbott, 2016; Delves*, et al.*, 2019; Leslie, 2012; Macutkiewicz and Sunderland, 2011; Mcguinness*, et al.*, 2019; Mcguinness*, et al.*, 2018; Mcmahon and Kennedy, 2019; Vescovi, 2016; Vescovi and Frayne, 2015).

Due to uneven playing times, relative distance ($m \cdot min^{-1}$) is a more appropriate way of comparing distances covered both within and across studies. Although the total distances covered in the present study were similar to International U16 and U17 teams, as seen in male academy footballers (Harley*, et al.*, 2010) the meters per minute were lower. International U16s female hockey players covered an average of 108 ± 6 $m \cdot min^{-1}$ (Leslie, 2012) and U17's 107 ± 9 $m \cdot min^{-1}$ (Vescovi, 2016) compared to 85 ± 19 $m \cdot min^{-1}$ in the present study. However, match intensity measured within the present study was considerable, between 46.4 $m \cdot min^{-1}$ and 114.1 $m \cdot min^{-1}$, suggesting a high range of abilities within this group of players. Vinson*, et al.* (2018) compared relative distance covered by UK club female hockey players (tier 3/4) against different standard of opponents and found that lower relative distances were covered in all positions when playing against similar standard opposition. This may have been an influence in the present study, where all matches were selected to be against opposition of a similar standard and data was collected from both teams. In previous studies, the structure of the game has been found to impact intensity of play, International players (tier 4/5) in games played as two 35 minute halves have recorded relative distances of 115.4 ± 23 $m \cdot min^{-1}$ (Macutkiewicz and Sunderland, 2011) compared to relative distances as high as 145 $m \cdot min^{-1}$ in games played as four 15 minute quarters (Mcguinness*, et al.*, 2019; Mcguinness*, et al.*, 2018). The long warm up times and distances covered by some players in the present study may have acted to reduce match intensity and this should be investigated further. Warm up distance was negatively correlated with both time on the pitch in the second half and total time on the pitch time, but this may have been due to the greatest warm-up distances being covered by forwards, who are also generally substituted more often.

Many previous studies in adult hockey players have split distances covered by playing position, forwards covering 115-146 $m \cdot min^{-1}$ compared to midfield players 105-138 $m \cdot min^{-1}$ and defensive players 100-123 $m \cdot min^{-1}$ (Abbott, 2016; Mcguinness*, et al.*, 2019;

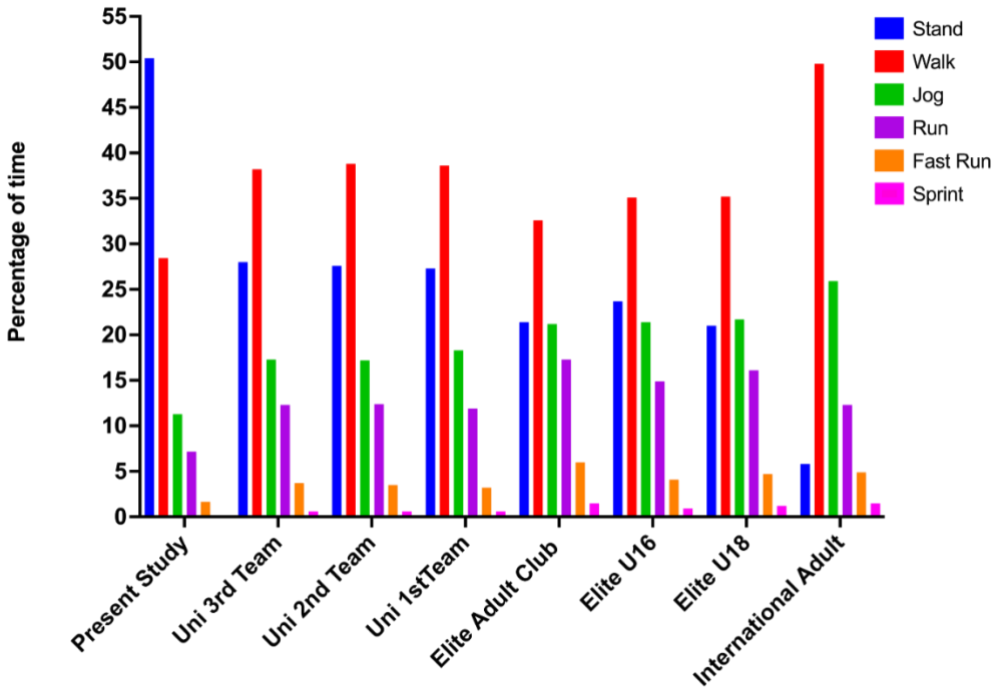
Mcguinness*, et al.*, 2020). The same relationship is seen in club, sub-elite and U17 college teams, with forwards and midfield players spending less time on the pitch but covering greater $m \cdot min^{-1}$ (Abbott, 2016; Delves*, et al.*, 2019; Mcguinness*, et al.*, 2018; Vescovi, 2016; Vescovi and Frayne, 2015; Vinson*, et al.*, 2018). This relationship was not seen in the present study, with no significant difference seen between playing positions, and a range of $m \cdot min^{-1}$ values measured in each position (Forwards 63-109 $m \cdot min^{-1}$, Midfield 60-112 $m \cdot min^{-1}$, Defence 47-114 $m \cdot min^{-1}$). This lack of relationship has also been found in young football players (Atan*, et al.*, 2014) and may reflect that at this age, players are not necessarily playing in the position that they will play in later and that during adolescence players will change and develop at different rates. However, forwards in the present study did have the highest maximum speed (22.6 ± 0.85 $m \cdot s^{1}$, range 21.5-23.5 $m \cdot s^{-1}$), significantly higher than either defenders (20.3 ± 2.2 $m \cdot s^{1}$, $p < 0.005$) or midfield players (20.8 ± 1.4 $m \cdot s^{1}$, $p < 0.001$) which was in keeping with findings in adult hockey players (Mcmahon and Kennedy, 2019; Vescovi, 2014; Vescovi and Frayne, 2015; Vinson*, et al.*, 2018).

Regardless of the velocity bands used in games of 70 minutes, International, university and club female adult hockey players have been found to spend 92-98% of match time in low or moderate intensity movement; standing, walking, jogging or running (Gabbett, 2010; Leslie, 2012; Macleod*, et al.*, 2007; Macutkiewicz and Sunderland, 2011). The present study, in line with these findings, found 97% of pitch time in low or medium velocity movement bands but the degree of low intensity movement, particularly standing, is higher than recorded elsewhere.

Figure 4.2 illustrates the percentage of time spent in each of the velocity bands; standing, walking, jogging, running, fast running and sprinting in the present study compared to Loughborough University players playing in the top three teams, Premier League players, National Age Group International U16, U18s, (Leslie, 2012) and International adult GB players (Macutkiewicz and Sunderland, 2011). The amount of low intensity

activity has been identified as a key difference between elite (tier 4/5) and non-elite (1/2/3) games; the top players spending 50-57% of time standing or walking (Gabbett, 2010; Leslie, 2012; Macutkiewicz and Sunderland, 2011; Mcguinness*, et al.*, 2019) compared with over 60% of time in sub-elite players (Leslie, 2012). U16 National Age Group international players are recorded spending 58.7 ± 2.5% in low intensity bands (23.7 ± 1.6% standing, 35.1 ± 1.4% walking) (Leslie, 2012) compared with 79% the present study (50.4 ± 10.0% standing, 28.4 ± 5.8% walking).

Figure 4.2 Comparison of the percentage of pitch time in each velocity band in adolescent hockey players (present study), University 3s, 2s, 1s, Premier League Club players and National Age Group U16 and U18 International juniors (Leslie (2012), and Female UK Internationals (Macutkiewicz and Sunderland (2011). Data expressed as mean values.



The velocity bands used in the present study to describe the different movement intensities were modified by Leslie (2012) to better represent the speeds of younger and female players, thresholds taken from male team sports having been found to reduce

the proportion of higher-speed activities (Bradley and Vescovi, 2015). In the adjustment by Leslie (2012), the lower intensity velocities were left unchanged from those used in previous studies in hockey and football (Leslie, 2012). The velocity bands used in the present study to describe standing are 0-0.83 $m \cdot s^{-1}$ and walking 0.86-1.66 $m \cdot s^{-1}$. Normative data for walking speeds in children and adolescent girls age 13-19 identify slow walking as 0.95 ± 0.14 $m \cdot s^{-1}$, 'normal walking' as 1.22 ± 0.15 $m \cdot s^{-1}$ and fast walking as 1.64 ± 0.27 $m \cdot s^{-1}$ (Waters, Lunsford, Perry, & Byrd, 1988) all of which would be correctly classified as walking within the present velocity banding, however many other studies in women's hockey, rugby and football have used a narrower description of standing as <0.2 $m \cdot s^{-1}$ (Abbott, 2016; Clarke*, et al.*, 2015; Datson*, et al.*, 2017; Dwyer and Gabbett, 2012; Holmes, 2011; Macutkiewicz and Sunderland, 2011; Mcmahon and Kennedy, 2019) or have not attempted to split standing and slow walking, including both in a low activity band (Gabbett, 2010; Mcguinness*, et al.*, 2019). The measurement of speed within GPS is found to be accurate within 0.0 ± 0.25 $m \cdot s^{-1}$ (Macleod*, et al.*, 2009), but the very high proportion of time recorded as standing in the present study should still be treated with caution. It is likely that the players were moving but that this was at low levels of acceleration, and it is possible that the description of low velocity movement bands for use in junior sport should be revisited. This would be supported by the measured minimum heart rates in the present study, which are consistently higher than 50% of HR_{MAX} and over 100 $beats \cdot minute^{-1}$ (ACSM 2017; Waters*, et al.*, 1988).

In line with the majority of studies in female adult hockey players (Macutkiewicz and Sunderland, 2011; Mcguinness*, et al.*, 2019; Vescovi, 2014; Vescovi, 2016; Vinson*, et al.*, 2018), forwards in the present study did a greater proportion of high-speed running, spent more time in high intensity bands than defenders or midfield players, and recorded greater maximum velocity. Not all studies have identified forwards as doing the highest proportion of high speed running (>5 $m \cdot s^{-1}$). Gabbett (2010) and (Abbott, 2016) recorded midfield players spent the most time in the top velocity band. Macutkiewicz and

Sunderland (2011) concluded that the higher time spent in moderate to high intensity movement by players was directly related to a higher substitution rate and so is dependent on tactics as much as player type or position. This finding is supported by recent research comparing the intensity in play in games played as four 15 minute quarters, with the traditional format of two 35 minute halves (Abbott, 2016; Mcguinness*, et al.*, 2020). Linke and Lames (2016) investigating the movement of male hockey players and the effects of substitution identified the 'first-minute-rush-effect' where players exceeded the average distance covered by ~13% in the first minute after joining the pitch due to the necessity of reaching their position and catching up with play, suggesting that this distorted movement figures. In this study, the time on pitch and number of substitutions was no different between positions, possibly suggesting that this effect is less prominent in junior games where positions are less tightly held. It is also possible that the developmental aims of age group leagues, the equal rotation of players in all positions or the greater proportion of time played by older or stronger players influenced our results. Hoppe, Baumgart, Slomka, Polglaze, & Freiwald (2017) concluded that adaptiveness to the team tactics was a possible limiting factor in explaining the lower total distances covered and EE in elite (tier 4/5) Bundesliga footballers during preseason friendly games. Players in the current study will only play with this age group team occasionally and are likely to be playing for multiple teams at school and club for different coaches, making their roles less defined.

Focusing on distance covered and intensity of play fails to fully account for the energy cost of key features of team sport match-play; accelerations, decelerations, jumps, turns, dribbling and contact usually being classified as low-speed activity despite evoking high physiological load (Beenham*, et al.*, 2017; Osgnach*, et al.*, 2010) . In the present study, metabolic power was estimated using embedded algorithms with the Catapult GPS system using equations proposed by Di Prampero*, et al.* (2005), and modified by Osgnach*, et al.* (2010) . This method has been previously used in adult football

(Osgnach*, et al.*, 2010) and hockey (Polglaze*, et al.*, 2017; Vescovi, 2016) but is controversial. Validation studies have frequently found that algorithms overestimate the energy cost of walking and underestimate the cost of high-intensity multi-directional movement patterns and have questioned its use (Brown, Dwyer, Robertson, & Gastin, 2016; Buchheit*, et al.*, 2015; Costello *et al.*, 2019; Highton*, et al.*, 2017; Oxendale, Highton, & Twist, 2017). However, it is generally accepted that it is more accurate than any of the possible alternatives (Di Prampero and Osgnach, 2018; Highton*, et al.*, 2017; Polglaze*, et al.*, 2016) and modern algorithms are increasingly accurate (Di Prampero and Osgnach, 2018; Polglaze*, et al.*, 2016).

EE calculated in the present study was 8.0 ± 2.0 kcal·kg^{-1}, 452 kcal for the match. In the present study there was no difference in EE between forwards (8.5 ± 1.7 kcal·kg^{-1}, 436 kcal·match^{-1}), midfield (8.6 ± 1.8 kcal·kg^{-1}, 461 kcal·match$^{-1)}$ and defenders (8.2 ± 2.5 kcal·kg^{-1}, 456 kcal·match^{-1}). Vescovi (2016) measured comparable match EE in U17 Canadian Internationals (tier 3/4) at U17 (5.5 ± 2.0 kcal·kg^{-1}, 314 kcal·match^{-1}) and U21 (6.5 ± 1.2 kcal·kg^{-1}, 413 kcal·match^{-1}) and found forwards expended less energy than midfield or defensive players. This relationship was also found by Polglaze*, et al.* (2017) analysing male Australian internationals with EE for all players of 7.6 ± 0.9 kcal·kg^{-1}, 585 kcal·match^{-1}. Although there are clear differences, the present studies values are close to those found in other hockey studies when compared with values in football, 14.6 kcal·kg^{-1} (Osgnach*, et al.*, 2010), Australian football 13.6 to 14.5 kcal·kg^{-1} across positions (Coutts*, et al.*, 2015) and male rugby league 6.1 to 10.3 kcal·kg^{-1} (Kempton*, et al.*, 2015). This difference has been explained by the shorter games, smaller playing area and unlimited substitution (Polglaze*, et al.*, 2017). However, it is also worth noting that the model does not take into account the added cost of dribbling in hockey, which is known to increase oxygen consumption by 15% compared to running at the same speed (Reilly and Seaton, 1990) and assumes a set economy of running, although this can change considerably during childhood and adolescence (Krahenbuhl and Williams,

1992). The present study found no difference between positions but a trend towards lower EE in forwards than midfield or defensive players (436 kcal·match^{-1} vs 461 kcal·match^{-1} and 456 kcal·match^{-1}, p=0.86). This relationship has also been found in football (Hoppe*, et al.*, 2017; Osgnach*, et al.*, 2010) and has been related to the higher body mass and greater height of defensive players (Hoppe*, et al.*, 2017).

This was the first study to investigate movement profiles and the energy demand in female adolescent hockey players and provides useful information both for the design of future training schemes and to allow discussion of how matches and training can best be nutritionally provisioned. The main limitation within the present study is the small number of data points. Although four matches were analysed, with the ambition of 100 data points it was evident from the initial two games that there was a skew in the participants who agreed to be included in further data collection after feedback had been given. Players with poorer feedback being reluctant to have their data analysed in subsequent games, to limit this biasing effect every participant within the study was only monitored once.

The velocity bands used to assess the intensity of movement in the present study were chosen to map with those used by Leslie (2012) in female and adolescent hockey players and have been used in recent studies in male adolescent players (Van Der Merwe and Haggie, 2019; Wylde, 2014). In the present study, the percentage of time in low and medium intensity bands was substantially higher than in other studies using the same velocities in young international and club players (Leslie, 2012). The amount of time spent standing was particularly high at 50.4 ± 10.0% of pitch time. The lower velocity bands are in keeping with the available research on movement speeds in children and adolescents (Schwartz, Rozumalski, & Trost, 2008; Waters*, et al.*, 1988) but within a game setting where movement may be multidirectional, it may be more appropriate to

use a lower velocity description of standing or just three bands describing low, moderate and high intensity activity, rather than looking to sub-divide this further.

The use of metabolic power to measure EE is not yet been validated within hockey and the present study, like previous research found that the energy cost of hockey is lower than other team sports (Coutts*, et al.*, 2015; Kempton*, et al.*, 2015; Osgnach*, et al.*, 2010). This may be explained by the shorter games, smaller playing area and unlimited substitutions in hockey (Polglaze*, et al.*, 2017) but some caution should be given as the current model of metabolic power may underestimate the cost of the bent stance required when dribbling a ball. Previous studies in adult games have identified higher recorded meter per minute distances than other comparable team sports (Mcmahon and Kennedy, 2019) and high recorded heart rates for intensity of play (Mcguinness, Malone, Hughes*, et al.*, 2017). Warm up times have not been recorded in previous studies but were high, with 24% of all players and 46% of forwards covering over a 1,000 m distance. The warm-up was not included in the analysis of match demands and the energy cost of the warm-up would also add to total EE of this group and should be included in future research.

In summary, Catapult GPS were used to analyse the activity profile and EE in female adolescent hockey players playing in an U16 league. Time on the pitch was found to be similar to that measured in both university and adult female games but the intensity of play was lower, with a much higher proportion of match time being spent standing, and lower relative distances covered ($m \cdot min^{-1}$). No difference was found between players by position but there was a wide range in the distances travelled and relative distance covered for each playing position. Although a relatively low number of players and matches were analysed these findings give an insight into the demands of female adolescent hockey games, to aid practitioners to create practical advice on how best physically prepare and provide nutritional advice to fuel for matches and recover post-

game. Across all measures there was a wide range of performances, with some players recording match intensities and distances equivalent to those seen in female international players. This emphasises the need for personalising nutritional advice to the individual and highlights that within club hockey there are some individuals who may require specialist support to ensure that they are getting adequate nutrition support. As indicated by the MSFT and SlalomSDT results in Study 1, hockey specific performance in this group is not related to age, and the results from the present study show that match performance; distance, relative distance and time spent in higher velocity zones, is also not related to position and caution should be taken in generalising across groups.

The mean EE calculated from metabolic power in the present study was high (452 kcal·match^{-1}). Adolescents who participate in organised sport have higher nutritional demands than non-athlete peers of the same age (Hannon*, et al.*, 2019). Despite higher requirements adolescents often engage in inappropriate dietary strategies (WHO, 2005) and adolescent athletes are known to be at higher risk of disordered eating (Kontele and Vassilakou, 2021). LEA where the body does not have enough energy available after subtracting EEE to support all the physiological functions needed for optimal health should be avoided (Wasserfurth, Palmowski, Hahn, & Krüger, 2020).

The present study gives good information to inform advice given for match performance, and fueling for the work required, but all nutrition advice needs to fit into the context of general nutrition intake and should not be thought of as a stand-alone provision. When personalising recommendations, it is important not just to look at one match or sport, and to know how an individual's sport fits into the context of their other activity. Nutritional intake is measured over a four-day period in Study 3 and both physical activity and eating behaviour is investigated in Study 4 of this thesis. Obtaining more information about current behaviour is important to allow appropriate science backed advice to be given.

5. STUDY THREE: Habitual Dietary Intake in Adolescent Female Hockey Players.

5.1 Abstract

The aim of this study was to document the in-season dietary intake of a group of adolescent female hockey players to assess, eating habits, dietary adequacy and the distribution of energy and macronutrient intakes over the day. **Methods**: Twenty-four female participants, 13.4 ± 0.6 yr; height 1.63. ± 0.07 m, body mass 54.1 ± 7.5 kg completed a self-report food and activity diary, including 2 consecutive weekdays and 2 days at the weekend during an in-season period. Total Energy Intake (EI) macronutrient composition and intake of fruit and vegetables (FV) were quantified. Timing of macronutrient intake was split into breakfast (B), morning snack (MS), lunch (L), afternoon snack (AS), supper (S) and an evening snack (ES). Dependent variables were calculated, described as the mean and standard deviation, and compared using paired sample T-test and Pearson's correlations. **Results**: Total energy, EI per kilogram body mass, carbohydrate intake, FV consumption and fibre intake were all lower than the predicted requirement in this group. Total fat, saturated fat and sugar intake were higher than recommended. Protein intake as a proportion of total EI was higher than recommended for the general population but was in line with recommendations for junior intermittent team sport athletes. **Conclusions**: This was the first study to quantify the habitual dietary intake in female adolescent hockey players. Like studies in other team sports, total EI was below estimated EE and was poorly distributed across the day. Intake of carbohydrates were well distributed but lower than would be recommended for activity level and although protein intake was high it was skewed towards evening meals.

5.2 Introduction

Quantifying energy and nutrient intake are crucial to inform evidence-based strategies to support adolescent athletes. This is particularly important in this population as there are key anatomical, physiological and metabolic differences between child or adolescent athletes and adults (Hannon, Close*, et al.*, 2020; Hannon*, et al.*, 2019) and not always

the research available to formulate strong advice (Desbrow*, et al.*, 2019). Adequate dietary intake is important for sports performance, and it is also vital to ensure optimal growth and development in this age group (Logue*, et al.*, 2018; Rosenbloom*, et al.*, 2006; Thomas*, et al.*, 2016).

The adequacy of nutrient intake in UK adolescents has been shown to be sub-optimal. The National Diet and Nutrition Survey (NDNS) 2018 found that female adolescents in the UK aged between 11 and 18 yr have the poorest diets of any age group, with low EI, low FV consumption (2.8 ± 1.6 portions·day$^{-1)}$ and high consumption of saturated fat (12.2% ± 2.9 total food energy) and added sugar (14.4% ± 6.1 total food energy) (NDNS, 2018). Several studies have shown that junior athletes' diets are also inadequate compared to both National dietary guidelines and sport nutrition recommendations (Gibson*, et al.*, 2011; Zalcman*, et al.*, 2007), with particularly low FV intakes (Abbey, Wright, & Kirkpatrick, 2017; Aerenhouts*, et al.*, 2011; Aerenhouts*, et al.*, 2008; Rosen, Frohm, Kottorp, Friden, & Heijne, 2017; Smith, Jones, Sutton, King, & Duckworth, 2016).

A high proportion of highly trained adolescent athletes are also identified as having too low EI and being at increased risk for eating disorders (Bratland-Sanda and Sundgot-Borgen, 2013; Knapp*, et al.*, 2014; Melin*, et al.*, 2014; Sundgot Borgen and Torstveit, 2010; Sundgot-Borgen and Torstveit, 2004). The accurate calculation of energy needs is crucial when giving advice to adolescent athletes. As well as being important for performance, the accurate estimation of individual energy needs has been linked to improved immunity (Walsh*, et al.*, 2011), reduced susceptibility to injury (Ihle and Loucks, 2004; Thein-Nissenbaum*, et al.*, 2011), beneficial endocrine changes (Degoutte*, et al.*, 2006) and lower menstrual disturbance (Reed*, et al.*, 2013). Sufficient EI is crucial for training consistency and performance particularly during periods of intense training or competition (De Souza*, et al.*, 2014; Logue*, et al.*, 2018; Logue*, et al.*, 2020; Mountjoy, 2018). Prolonged energy restriction can lead to impaired physiological function,

increased risk of fatigue, illness or injury and poor adaptation to training (Bergeron*, et al.*, 2015; Mountjoy, 2018; Mountjoy*, et al.*, 2014). Energy homeostasis and consistency of intake are also linked to appetite and subsequent EI, under-fuelling leading to the potential of poor dietary choices (Blundell*, et al.*, 2015; Keesey and Powley, 2008).

In the position statement on nutrition in adolescent athletes and in subsequent reviews, Desbrow *et al* (2014 & 2021b) concluded that the primary focus for practitioners working with young athletes should be to ensure that the nutritional requirements for growth and maturation are met. Highly variable rates of growth and maturation exist between young athletes particularly around PHV which impact energy needs (Malina and Geithner, 2011) and the high metabolic variability between individuals makes estimating EE difficult (Petrie*, et al.*, 2004). Ensuring EI matches EE, maintaining EB, is a special concern for growing female athletes because of the risk of Relative Energy Deficiency in Sport (RED-S) (Logue*, et al.*, 2020; Mountjoy*, et al.*, 2014). In Study 1, all participants were within 2.5 yr of their peak growth phase and all but one was below predicted peak adult height and so still growing. In Study 2, calculated EEE for the match was high (452 kcal·match^{-1}) when compared to the mean estimated daily EE for this group (2,173 ± 131 kcal·d^{-1}). Adequate EI is key to ensure the cost of all activity is covered and is also important when making recommendations on protein intake; sub-optimal EI causing endogenous protein to be used to maintain blood glucose, preventing its use for its primary roles (Desbrow, 2021b).

Published literature investigating nutritional adequacy in female hockey players is limited, with only four studies including adult female hockey players (Nutter, 1991; Tilgner and Schiller, 1989; Van Erp-Baart*, et al.*, 1989; Wardenaar*, et al.*, 2017) . All these studies have been on mixed-gender athletic populations and not specifically focused on the hockey players but all have concluded that EI is lower than recommended (Nutter, 1991; Tilgner and Schiller, 1989; Van Erp-Baart*, et al.*, 1989; Wardenaar*, et al.*, 2017).

Of these only Wardenaar *et al* (2017), included young players, analysing the macronutrient intakes in 553 young Elite (tier 4/5) Dutch athletes, 11 who were female hockey players (age 18.5 ± 0.8 yr) and finding lower than recommended carbohydrate and protein intakes. Research in adolescent academy football players has found that junior male (Boisseau*, et al.*, 2002; Boisseau*, et al.*, 2007; Briggs, Rumbold*, et al.*, 2015; Iglesias-Gutiérrez*, et al.*, 2005; Leblanc*, et al.*, 2002; Naughton*, et al.*, 2016; Ruiz*, et al.*, 2005; Russell and Pennock, 2011) and female players (Braun*, et al.*, 2018; Clark*, et al.*, 2003; Gibson*, et al.*, 2011; Parnell*, et al.*, 2016; Reed*, et al.*, 2014) also rarely meet their energy requirements and regularly have carbohydrate intakes below optimal levels.

The total amount of carbohydrate and protein intake are important, but the daily distribution of macronutrient intake may also be key in modulating training adaptation, match performance and recovery (Kerksick *et al.*, 2017). The effect of the timing of carbohydrate intake on pre-exercise loading and performance is well documented (Burke*, et al.*, 2011; Jeukendrup, 2014) and there is growing evidence that the timing of protein intake may also be important for muscle protein synthesis and recovery (Areta*, et al.*, 2013; Buckner, Loenneke, & Loprinzi, 2018; Churchward-Venne, Murphy, Longland, & Phillips, 2013; Jager *et al.*, 2017; Jennings, Nepocatych, Ketcham, & Duffy, 2016; Mamerow*, et al.*, 2014; Philippou, Middleton, Pistos, Andreou, & Petrou, 2017; Schoenfeld, Aragon, & Krieger, 2013). During heavy training and when in negative energy balance there is evidence that the timing of intake may be more important than the overall amount (Antonio *et al.*, 2020; Hector and Phillips, 2018). There is currently no published research on the timing of macronutrient intake in adolescent hockey players.

Study 1 identified that this population of female adolescent hockey players would be defined as athletes (Mountjoy*, et al.*, 2008), and as such may require specialist nutritional support. Knowing current dietary behaviour is key to give context to this provision, ensuring the right advice is given for both health and optimal performance. Study 1 also

identified the group as 'still growing' and in the light of Study 2, which confirmed that hockey is a high intensity intermittent team sport, it is important that dietary intake is adequate to allow growth and development as well as fueling required activity. The aim of this study is to document the in-season dietary intake of a group of adolescent female hockey players to assess, (1) adequacy of energy and macronutrient intake, (2) the distribution and timing of macronutrient and energy intake across the day.

5.3 Methods

5.3.1 Participants

Twenty-four female participants 13.4 ± 0.6 yr; height 1.63. ± 0.07 m (1.52 – 1.76 m); body mass 54.1 ± 7.5 kg (44.5 – 67.4 kg) volunteered to participate and keep a detailed four-day food and activity diary during the 2014/15 hockey season. All participants were registered in England Hockey's Single system and playing at County Junior Development Centre (JDC) level or higher. Ethical approval for the study was obtained from the University of Chichester Research Ethics Committee. All participants were given a written and verbal briefing on the purpose of the study and provided written informed consent.

5.3.2 Study Design

With participants wearing light clothing and no shoes standing height was measured to the nearest 0.01 m (Harpenden G133 Portable stadiometer, Holtain ltd, Dyfed, UK) and body mass was measured to the nearest 0.1 kg (Mettler Toledo PB3001-s Scales, Fisher Scientific UK).

To estimate mean daily intake of energy, nutrients, and food items, a 4-day food and activity record was used, including two weekdays and two days at the weekend.

Participants were instructed to maintain their normal eating patterns, to report all food and drink consumed as accurately as possible, and to provide the time of the day, portion size, preparation and ingredients contained within homemade foods. Additional information on the type, time and duration of physical activity was also requested. The participants and their parent/guardian were shown the printed diaries individually and guided through the instructions. It was made clear that although there was no need to weigh food items, it was important to give as much detail as possible and to gauge portion sizes using standard household measures, or by giving packet size and the proportion of the packet eaten. Parents/guardians were asked to oversee the diary where possible and check the entries were complete before it was returned. The participants then took the diary home. They were asked to return the diaries by post and to include any food packages or extra information that might be helpful for their analysis. On return of the food and activity diary, a second pass method was used where the diary was checked for missing detail and participants contacted by email to provide clarification where necessary.

5.3.3 Food diary Analysis

Food diary data was analysed using the Nutritics professional diet analysis software (Nutritics Ltd, Ireland). All analysis was carried out by a single trained researcher (TS) so that any potential variation in interpretation was minimised (Deakin, Kerr, & Boushey, 2000). Diaries were initially analysed for total energy and macronutrient content and then macronutrients amounts were recalculated split by the time that the food items were eaten. In this secondary analysis, meals were split into breakfast (B), morning snack (MS), lunch (L), afternoon snack (AS), supper (S) and an evening snack (ES). Time and type of consumption was used to distinguish between meals as outlined below:

B = ‘Breakfast’ - main meal consumed between 6-9.30am,
MS = ‘Morning Snack’ -foods consumed between breakfast and lunch
L = ‘Lunch’ - main meal consumed between 11.30-1.30pm
AS = ‘Afternoon Snack’ - foods consumed between lunch and supper

S = ‘Supper’ - main meal consumed between 5-8pm
ES = ‘Evening Snack’ - foods consumed after dinner and prior to sleep

These are the same time periods used as Naughton *et al* 2016 and Anderson*, et al.* (2017). In this secondary analysis, three of the food and activity diaries were not included as detail on the timing of intake was missing on one or more of the days and could not be completed on additional questioning.

To identify and record poor validity, participants were classified as under-reporters, average reporters or over-reporters from their individual ratio of reported EI to TEE according to (Black, 2000). Average reporters were identified by an EI/TEE ratio of 0.76-1.24, under-reporters by a ratio <0.76 and over-reporters >1.24. Percentage difference between the EI on the highest and lowest intake of the four days was also calculated.

5.3.4 Energy Expenditure (EE)

BMR was calculated according to the modified Schofield Equations proposed by Henry also known as the Oxford Equations (Henry, 2005). Schofield Equations are regularly used in athletes and have been shown to be valid when used in children and adolescents (Rodriguez*, et al.*, 2002). A physical activity level (PAL) of 1.6 was used to reflect moderate activity. This was defined as doing three days a week of high intensity training or five days moderate intensity in intermittent team or field-based sports and was checked against self-reported activity given within the food and activity diaries. In healthy, mobile individuals, the overall range of PAL values is between 1.38 and 2.5 (SACN, 2011). Whilst some criticism of the PAL x BMR approach has been expressed (Goran, 2005), no satisfactory alternative has yet been identified (SACN, 2011). Using a self-report activity protocol has been validated against indirect calorimetry and doubly labelled water (Koehler *et al.*, 2010).

5.3.5 Statistical Analysis

Data was collected from 21 adolescent female hockey players and was analysed using Statistical Package for Social Sciences (SPSS), Version 21. Data was checked for skewness and kurtosis and found to be normally distributed. A Pearson Correlation was used to examine the strength of the linear relationship between dietary intake of the different macronutrients before and after 1.30pm. In accordance with Cohen (1988). a correlation of >0.5 was classified as large, 0.5-0.3 as moderate. 0.3-0.1 small and anything smaller than 0.1 as insubstantial Dependent variables were calculated, described as the mean and standard deviation and intake for each macronutrient before and after 1.30pm was compared using paired sample T-test. Statistical significance was assumed at 5% ($p<0.05$).

5.4 Results

Only 21 of the participants completed and returned food and activity diaries. All of the returned diaries were classified as average-reporters (Black, 2000) and so accepted for analysis.

Figure 5.1 shows the distribution of macronutrients and energy expressed in absolute units and relative to body mass. Pearson correlations were used to examine the associations between intake before 1.30pm with the intake after 1.30pm. High overall EI before 1.30pm was positively associated with high intake of all nutrients before 1.30pm (CHO $r=0.8$, $p<0.001$, PRO $r=0.8$, $p<0.001$, and FAT $r=0.8$, $p<0.001$) but only with carbohydrate and protein intake after 1.30pm (CHO $r=0.8$, $p<0.001$, PRO $r=0.8$, $p<0.001$). Between nutrients, there was only a positive association between protein and fat intake before 1.30pm ($r=0.8$, $p<0.001$) but not between each nutrient after 1.30pm or

between other nutrients. The paired T-test showed there was no significant difference in EI, amount of carbohydrate or fat before and after 1.30pm but protein intake was significantly higher after 1.30pm ($t=-3.3$, $p<0.005$).

Table 5.1 Nutrient Intakes over a four-day period in female adolescent hockey players. Data expressed as mean ± standard deviation. Recommended intakes based on COMA (1991) values or those recommended for adolescent athletes (Desbrow, et al., 2014a). Estimated energy expenditure calculated using a Henry Equation (Henry, 2005) and selecting a PAL.

Nutrient	Mean ±SD	RNI / Advice
Estimated Energy Expenditure ($kcal \cdot d^{-1}$)	2131 ±224	2,725
Energy intake ($kcal \cdot d^{-1}$)	1920 ±335	N/A
Energy Balance ($kcal \cdot d^{-1}$)	-158 (7.4%) ±158	N/A
Fruit and Vegetables$\cdot day^{-1}$	3.6 ±1.4	5 +
Carbohydrate (%)	46 ±7.1	50-60
Carbohydrate ($g \cdot kg^{-1} \cdot d^{-1}$)	4.5 ±1.1	5-6
Protein (%)	19 ±6	10-15
Protein ($g \cdot kg^{-1} \cdot d^{-1}$)	1.6 ±0.4	1.3-1.8
Fat (%)	34 ±8	20-25 < 35
Fat ($g \cdot kg^{-1} \cdot d^{-1}$)	1.5 ±0.5	N/A
Sugar ($g \cdot d^{-1}$)	55 ±25	>11yr <30
Sugar (%)	11 ±5	5
Saturated Fat (g)	30 ±10	Women <20,
Saturated Fat (%)	13.3 ±3	<11%
Fibre (NSP) ($g \cdot d^{-1}$)	16.5 ±4.5	25

Figure 5.1 Daily Distribution of Energy and Macronutrient Intakes in adolescent hockey players. B=breakfast, MS=mid-morning snack, L=Lunch, AS=Afternoon snack, S=Supper and ES= Evening snack. Data expressed as mean values.

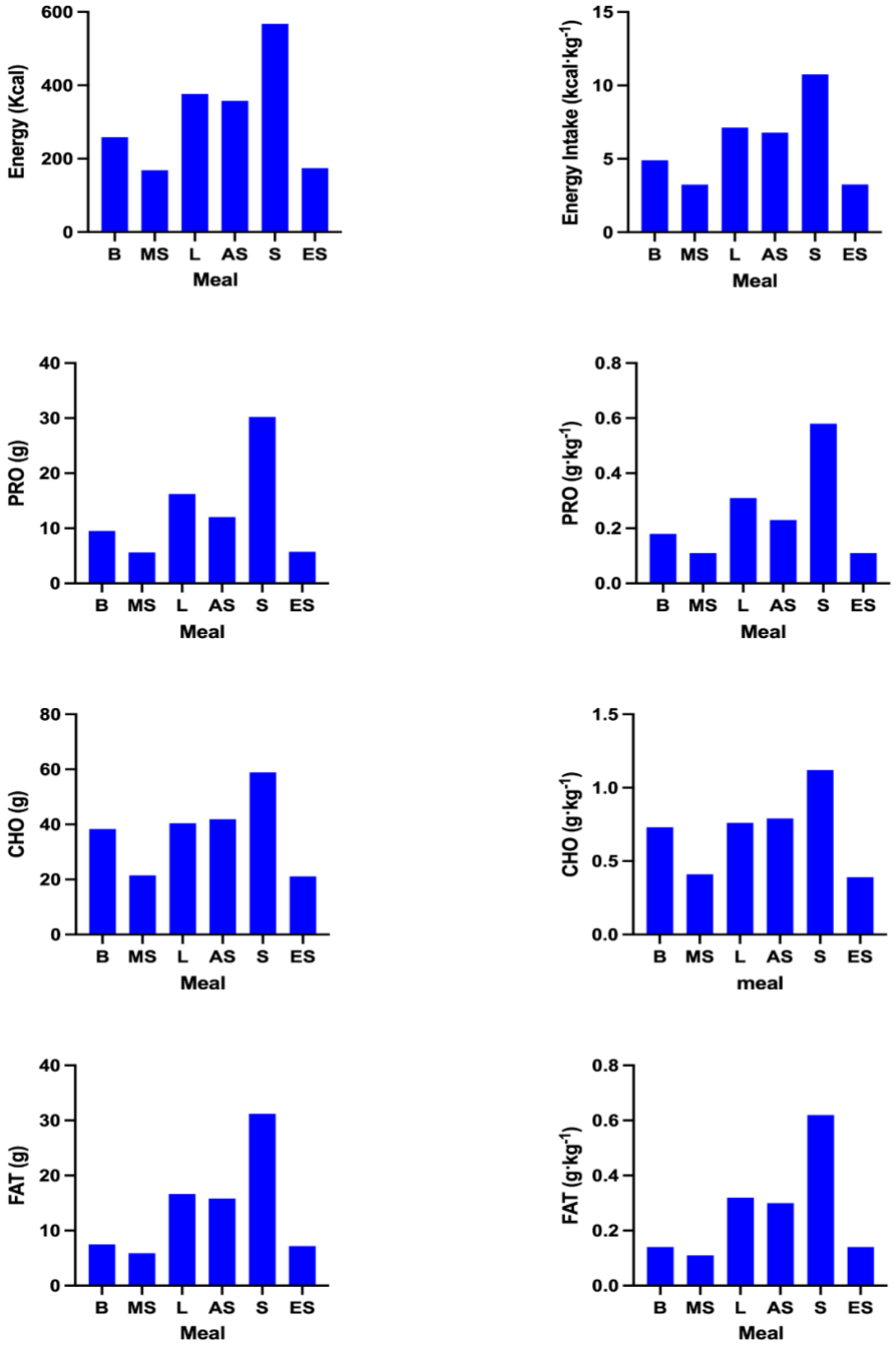


Table 5.1 shows energy and macronutrient intake expressed in absolute units and relative to body mass, FV consumption, fibre intake and the associated recommended nutrient intakes based on COMA (1991) values or those recommended for adolescent athletes (Desbrow*, et al.*, 2014; Desbrow, 2021a). Energy intake was below estimated energy requirements (1920 ± 335 vs 2131 ± 224 kcal·d^{-1}). Carbohydrate intake was lower than recommended for the general population (46% vs 50 - 55% and lower than would be expected for individuals who are moderately to highly active (4.5 g·kg^{-1}·d^{-1} vs 60%+, 5-6 g·kg^{-1}·d^{-1}). Fruit and vegetable consumption (3.5 ± 1.4 portions), sugar (11 ± 5%) and saturated fat intake (13.3 ± 3%) were all poor and suggested low diet quality.

Figure 5.2 Distribution of the percentage total intake (%) at in each timeframe, across the day for each macronutrient and for total energy intake compared with a model where energy intake is evenly distributed into 3 meals and 3 snacks. Data expressed as mean values.

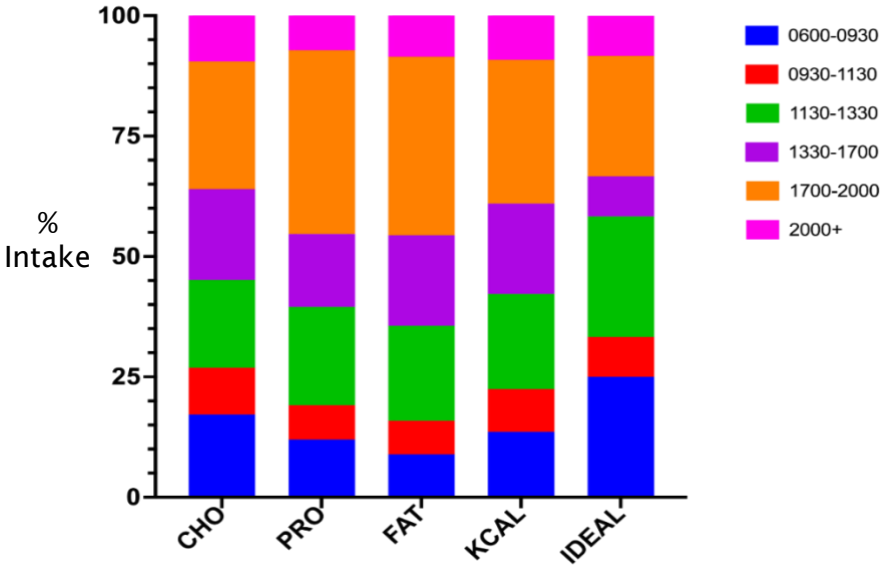


Figure 5.2 shows the distribution of macronutrients and total energy intake as a percentage of their total split over the different time frames of the day. These are

compared with a model of intake where EI is evenly split into three meals and three snacks. In this model EI is divided into four, with a quarter at each meal and the fourth quarter dividend between the three snack periods. Compared to this model EI is too low in the first half of the day.

Figure 5.3 Individual participant calculated energy balance (EI – EE) over four measured days. Data expressed as mean values.

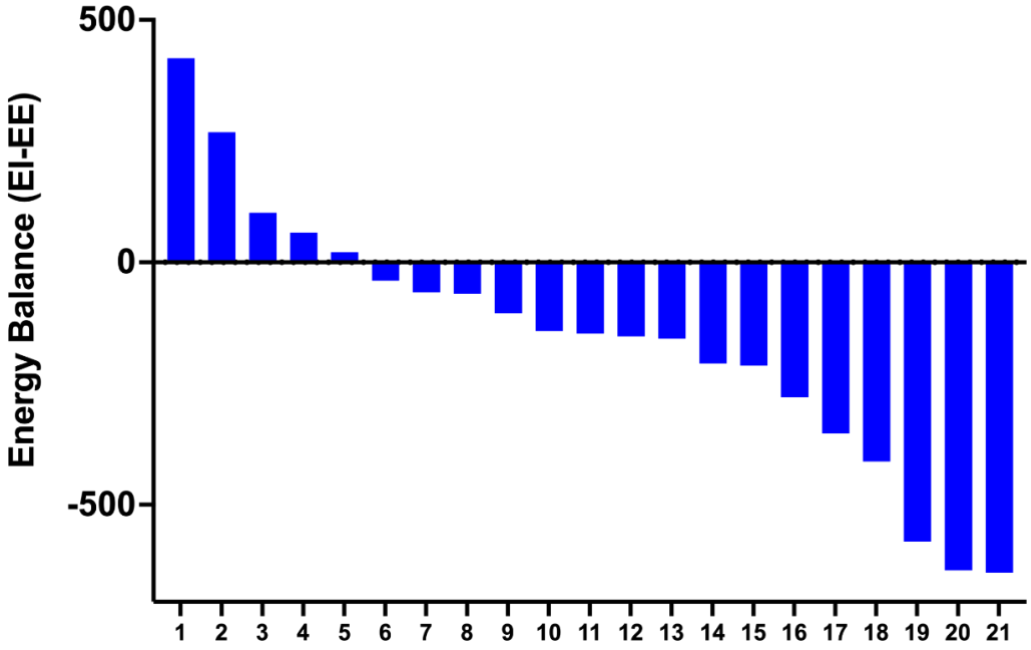


Figure 5.3 shows the individual EB over the four recorded days within the food and activity diaries. Only 5 participants were in positive EB, with the majority having lower than ideal EI.

5.5 Discussion

The present study is the first to quantify the estimated EE and dietary intake in female adolescent hockey players within the playing season. The quality of the dietary information reported was strong, with good information on food types and portion sizes

but the quality of the foods eaten was poor, with low intake of fruit and vegetables and high intakes of sugar and saturated fat.

Total EI was below estimated energy needs in 76% of participants in the present study. Studies on the accuracy of self-report food diaries consistently show underreporting of EI (Burrows, Ho, Rollo, & Collins, 2019) and adolescent girls are known to under-report their EI by between 20% and 30% regardless of whether self-reported, weighed or estimated food records are used (Bandini*, et al.*, 2003; Bandini*, et al.*, 1990; Bratteby*, et al.*, 1998; Livingstone*, et al.*, 1992). Livingstone, *et al.*, (1992) reported that having a parent checking the diaries, as done in the present study improves the accuracy of the detail recorded (Livingstone*, et al.*, 1992). Black (2000) assessed validity of food records by classifying the diaries as average, under and over-reported. All the diaries within the present study were counted as average reported and so included in the analysis, but caution should still be taken in when considering these values. There was high variation in EI across the days reported with a 62% (range 20-180%) difference in EI on the highest and lowest days measured and it is possible that the days selected were not representative of habitual intake.

The average daily EI in the participants in the present study was 1,920 ± 335 kcal·d^{-1} and when compared with the calculated mean estimated requirement of 2,131 ± 224 kcal·d^{-1} resulted in a mean energy deficit of 158 ± 284 kcal·d^{-1} or 7%. Energy requirements were estimated using BMR equations proposed by (Henry, 2005) and self-report activity levels. In the UK, there is no guidance on the energy requirements of active adolescent individuals, but the recommended age specific energy requirement listed by the World Health Organisation for high activity levels is 2,625 kcal·d^{-1} in 12-13 yr and 2,725 kcal·d^{-1} in 13-14 yr girls. These higher numbers may indicate that predictive equations underestimate energy requirements in this group. This is supported by studies in male academy footballers where Hannon, Carney*, et al.* (2020) have found that predictive

equations significantly underestimate RMR in young athletes. TEE measured using doubly labelled water over a 14 day measurement period found U12/13 academy footballers with mean EE of 2,703 ± 255 kcal·d^{-1} in week one and 3,122 ± 364 kcal·d^{-1} in week two (Hannon, Parker*, et al.*, 2020). There have been no equivalent studies in female adolescent team-sport, but these values are likely to be higher than those in the present study as although participants were playing high levels of organised sport, they were not doing the level of organised training expected in academy football.

Previous studies including hockey players have shown that EI is often below that recommended for EB (Nutter, 1991; Tilgner and Schiller, 1989; Van Erp-Baart*, et al.*, 1989). Negative EB has also been found in female adolescent volleyball players (Beals, 2002; Papadopoulou*, et al.*, 2002), female adolescent and college football players (Clark*, et al.*, 2003; Gibson*, et al.*, 2011; Mullinix*, et al.*, 2003) and 'talented' female adolescent team-sport athletes (Baker*, et al.*, 2013). Hinton*, et al.* (2004) examined nutrient intake and behaviour in collegiate athletes including 142 female athletes and reported 70% of female footballers were actively restricting EI with the aim of losing weight but neither Baker*, et al.* (2013) or Hinton*, et al.* (2004) included hockey players in their sample. Wardenaar*, et al.* (2017) did include 11 female hockey players (18.5 yr) in a study of 553 Dutch Elite (tier 4/5) and Sub-elite (tier 3/4) endurance, team and strength athletes but did not assess EE and no studies have been published looking at EB or energy status in this population. Rosen, Mckeag, Hough, & Curley (1986) reported that 50% of the female collegiate hockey athletes they studied demonstrated at least one pathogenic weight control behaviour but more recent studies have shown that despite an advantage in being lean, there is little evidence of greater risk of disordered eating within hockey (Marshall and Harber, 1996).

The UK National Diet and Nutrition Surveys in both 2016 and 2018 showed that female adolescents aged between 11 and 18 yr have the poorest diets of any age group, with

low EI, low FV consumption (2.8 ± 1.6 portions·day$^{-1)}$, high consumption of saturated fat (12.2 ± 2.9% total food energy) and intake of added sugar (14.4 ± 6.1% total food energy) (NDNS, 2018; NDNS., 2016). The present study found similar findings for saturated fat, with 13.3 ± 3% of daily calorie intake coming from saturated fats. The intake of sugar and FV in the present study, although still poor were slightly better than shown for adolescent girls within the general population, with an average intake of 3.6 ± 1.4 FV being consumed a day and a sugar intake of 11 ± 5% of total energy. Low FV intakes are common in adolescent athletes (Abbey*, et al.*, 2017; Aerenhouts*, et al.*, 2011; Aerenhouts*, et al.*, 2008; Rosen*, et al.*, 2017; Smith*, et al.*, 2016). As well as contributing to the low mineral and vitamin intakes commonly found in female athletes (Schneider, 2000) inadequate FV consumption has been independently linked to poor bone health (New, 2003) and increased injury risk (Rosen*, et al.*, 2017), and a higher intake is recommended.

The recommended intake of free sugar in the UK is 5% of EI, having been reduced from 10% in 2016. Excess intake of sugar is common in all athletes as it can be an intrinsic part of sports nutrition recommendations (Speiser *et al.*, 2005). The use of carbohydrate containing sports drinks is particularly common in children (Rodriguez, 2009; Schneider and Benjamin, 2011) and excess intake can both unbalance the diet and substantially increase the risk of tooth decay and weight gain. Female adolescent sprint athletes who consumed soft drinks have been found to have higher BF% than non-consuming athletes (Aerenhouts*, et al.*, 2008). Consumption of easily digested sugary carbohydrates and low FV intakes will compromise the intake of dietary fibre. Low fibre intakes are common in nutritional surveys of both female athletes (Heaney*, et al.*, 2010) and young male professional football players (Russell and Pennock, 2011). The present study found fibre intakes of just 16.5 ± 4.5 g·d^{-1}, well below the 25 g·d^{-1} recommended in the UK for this age group (COMA, 1991).

Macronutrient balance is an important part of a healthy diet. In the present study, the recorded diets consisted of 46 ± 7% carbohydrates, 19 ± 6% protein, and 34 ± 8% fat. This distribution of macronutrients is similar to previous studies in hockey players shown in Table 5.2 but represents a lower carbohydrate intake and higher fat intake than would be recommended in both adult (Kerksick *et al.*, 2018; Thomas*, et al.*, 2016) and adolescent athletes (Desbrow, 2021b; Desbrow, Burd, Tarnopolsky, Moore, & Elliott-Sale, 2018)

Table 5.2 Macronutrient distribution as a percentage of total Energy Intake in the present study compared to previous studies in elite (tier 4/5), college (tier 3/4), and youth female (tier 2/3) hockey players.

	Macronutrient Distribution (% of EI)			Mean kcal intake ($kcal \cdot d^{-1}$)
	CHO	PRO	FAT	KCAL
Present study – female English adolescent hockey players n=21. 4d food diary.	46	19	34	1,920 ± 335
Elite Female Dutch Hockey Players. n=9. 4d food diary (Van Erp-Baart*, et al.*, 1989)	46	19	35	2,152 kcal
USA Female College Athletes n=8. 3d food diary (Tilgner and Schiller, 1989)	47	16	39	1,856 ± 375
USA Female Hockey College. In-season. n=9. 3d food diary (Nutter, 1991)	45	15	27	1,513 ± 406
USA Female Hockey College. Post-season. n=9. 3d food diary (Nutter, 1991)	54	16	30	1,426 ± 394
Dutch National Youth Team Hockey n=11 female, 24hr recall or dietary questionnaire (Wardenaar*, et al.*, 2017)	53	17	30	2,091 ± 373

Poor carbohydrate intake is often found in young athletes and has been shown in adolescent male (Iglesias-Gutiérrez*, et al.*, 2005; Ruiz*, et al.*, 2005) and female football players (Clark*, et al.*, 2003; Gibson*, et al.*, 2011; Mullinix*, et al.*, 2003) as well as mixed

skill and team sport athletes (American football, football, basketball, lacrosse, golf and tennis) (Baker*, et al.*, 2013). The current advice for young athletes is the same as for adults and to "fuel for the work required" (Impey*, et al.*, 2018), personalising intake for the level of training and variety of sports played. Advice for the general population is to have 50-55% of EI as carbohydrate and this should be considered as the starting point. The broad advice for adolescent athletes is to have between 3 and 10 $g \cdot kg^{-1} \cdot d^{-1}$ (Desbrow, 2021b; Hannon, Close*, et al.*, 2020; Naughton*, et al.*, 2016). The present study found carbohydrate intake at just 46% of total EI and 4.5 $g \cdot kg^{-1}$ body mass. As a percentage this is below the recommended intake for optimal glycogen restoration (Zehnder, Rico-Sanz, Kühne, & Boutellier, 2001), at the lower end of recommended intake for adolescent athletes in the Sports Dietitian's Australia position statement (Desbrow*, et al.*, 2014) and for all ages by the American College of Sports Medicine (Thomas*, et al.*, 2016). However, on a $g \cdot kg^{-1}$ body mass, it would be considered to be within a healthy range (Nevin-Folino, 2003) and is in line with other female adolescent sport studies which show values between 3.0 to 5.5 $g \cdot kg^{-1}$ body mass (Cupisti, D'alessandro, Castrogiovanni, Barale, & Morelli, 2002; Papadopoulou*, et al.*, 2002; Wiita and Stombaugh, 1996). The 11 female youth hockey players (18.5 yr) included by Wardenaar *et al* (2017) had carbohydrate intakes of 4.2 ± 0.5 $g \cdot kg^{-1}$ body mass, very similar to the present study.

Recommended daily carbohydrate intake can be manipulated to promote high carbohydrate availability for specific training sessions or supplemented by acute fuelling strategies during training or competition (Thomas*, et al.*, 2016). The present study did not look at the distribution of carbohydrate intake compared to the timing of activity, but intake was found to be evenly distributed over the day regardless of where sports training or matches occurred.

The current recommendation for fat intake in adult athletes is 20-25% of total daily EI (Maughan and Shirreffs, 2011; Rodriguez, 2009) and despite some evidence that fat is more readily used as an energy substrate in both female and young athletes, there is currently no recommendation that female child or adolescent athletes should consume higher amounts of fat than adults (Briggs, Cockburn*, et al.*, 2015). The current advice to adolescent athletes is that consumption should be in line with current public health guidelines (30-35% fat), including the recommendation to favour intake of unsaturated fats from plant sources and fish, and to limit the intake of saturated fats (Desbrow, 2021a). The fat intake in the present study (34 ± 8%) was just within the population guidelines for total fat intake. Dietary fat intakes greater than 35% are not recommended as they can compromise carbohydrate intake (García-Rovés*, et al.*, 2014) or contribute to excessive weight gain (Je Quier, 2001). Intake of saturated fat in the present study (13 ± 3%) was higher than recommended intake of 11% of total daily EI. High saturated fat intake is often associated with unhealthy food consumption but can also be a consequence of high meat or dairy consumption. In the present study, fat intake in the first half of the day was positively associated with protein intake (r=0.8) and was largely attributed to milk intake, which has good nutrient density. The fat intake later in the day, particularly after 8 pm was identified as being part of snack food consumption, with lower nutrient value and this should be the focus of any fat reduction.

Adequate protein intake is particularly important in children and adolescent athletes to facilitate growth, muscle development and maturation on top of sport related adaptation (Bonci, 2010; Desbrow*, et al.*, 2014; Petrie*, et al.*, 2004). The current recommendation for the general population is that protein intake is 10-15% of total EI or 0.75-1.20 $g \cdot kg^{-1}$ body mass per day (WHO/UN, 2007). Adult athletes are known to have greater protein needs to maintain positive nitrogen balance and support growth than sedentary individuals (Hawley*, et al.*, 2006; Mettler*, et al.*, 2010; Phillips and Van Loon, 2011) and higher protein intakes have been reported in competitive and elite adult athletes of

between 1.2 – 2.0 $g \cdot kg^{-1} \cdot d^{-1}$ (Thomas*, et al.*, 2016). Nitrogen balance studies in adolescent male footballers and mixed gender adolescent sprint athletes have shown positive balance is achieved with intakes of 1.4-1.6 $g \cdot kg^{-1} \cdot d^{-1}$, (Aerenhouts*, et al.*, 2013; Boisseau*, et al.*, 2002; Boisseau*, et al.*, 2007), indicating they also have higher needs than the general population. When expressed relative to body mass, requirement in female athletes may be greater than their male counterparts due to normally higher proportions of body fat (Wooding *et al.*, 2017).

Protein intake in the present study was high (18.9 ± 6.2% of total daily EI or 1.6 ± 0.4 $g \cdot kg^{-1} \cdot d^{-1}$) and agrees with the findings for adolescent athletes in other studies (~1.2–1.6 $g \cdot kg^{-1} \cdot d^{-1}$), (Aerenhouts*, et al.*, 2011; Aerenhouts*, et al.*, 2013; Areta*, et al.*, 2013; Gibson, Mitchell, Harries, & Reeve, 2004; Heaney*, et al.*, 2010; Petrie*, et al.*, 2004). There is no evidence of any deficiency in protein intake in young British athletes, however, there is increasing evidence that the timing of protein intake is also important for recovery (Areta*, et al.*, 2013; Buckner*, et al.*, 2018; Churchward-Venne*, et al.*, 2013; Jager*, et al.*, 2017; Mamerow*, et al.*, 2014; Schoenfeld*, et al.*, 2013) and that the distribution of protein intake in both adult and junior athletes may be suboptimal (Anderson*, et al.*, 2017; Gillen*, et al.*, 2017; Naughton*, et al.*, 2016). Traditional protein intake guidelines have always been provided as $g \cdot kg^{-1}$ body mass, however newer recommendations are given to highlight that muscle adaptation is maximised by ingesting protein spread in meals across the day. The current ACSM recommendation is to consume 0.3 $g \cdot kg^{-1}$ after key exercise sessions and every 3-5 hours over multiple meals (Thomas*, et al.*, 2016). In the present study when the nutritional intake was divided into time periods across the day the intake was below this level other than between 11.30-13.29 (lunch = 0.31 $g \cdot kg^{-1}$) and 17.00-17.59 (supper = 0.58 $g \cdot kg^{-1}$) as shown in Figure 5.1 and was significantly lower in the first half of the day ($t = 3.3$, $p < 0.005$). Figure 5.2 shows that although energy, fat and carbohydrate intakes were all higher in the second half of the day, the only nutrient that was significantly uneven in distribution across the day was protein. Adequate total EI is

also vital if protein is to be available for training adaptation, muscle building and repair (Gibson*, et al.*, 2011). Comparison with an 'ideal' eating pattern in the present study showed lower than optimal energy intake in the first part of the day. Analysis of the dietary intake in male UK academy footballers during training and match days has also shown evidence of inadequate breakfast consumption (Anderson*, et al.*, 2017; Naughton*, et al.*, 2016), and poor early day nutrition has also been found in adult athletes (Gillen et al 2017, Garcia-Roves et al 2014). The International Society of Sports Nutrition Position Stands on nutrient timing and meal frequency emphasises the importance of evenly spreading EI across the day (Kerksick*, et al.*, 2017; La Bounty *et al.*, 2011) and this should be a focus of future advice in this age group.

There were several limitations in the present study. Although the design of the dietary data collection lowered the risk of some of the well reported inaccuracies of self-report food diaries, the accuracy of the method is still low and would have been further exacerbated by the small sample size. In addition, the physical activity level used to calculate energy requirement was also selected by self-reported activity. Choosing a physical activity level in children is challenging as activity is often found to be intermittent and sporadic (Hills, Mokhtar, & Byrne, 2014) and very little is known about how wider eating habits in this age group relate to their sport participation or how their sport and other commitments were impacting their nutritional intake. The majority of participants in the present study had EI below their estimated requirements but there was some uncertainty as to the accuracy of estimates of physical activity. This limitation will be addressed in Study 5 with the concurrent measurement of physical activity and dietary intake.

The way that foods were reported and the detail of meals within the food diaries collected were good, the ability to question participants on their intake also allowed missing detail to be added. However, there was some evidence that participants had selected the days

that they included to be “more normal”, and this may not have given a true reflection of their usual diet. This will be investigated further in Study 4 and 5 with more information collected on eating behaviour and physical activity, and how these relate to each other.

In conclusion, this is the first study to quantify the in season dietary intake in female adolescent hockey players. Total EI was slightly lower than the recommended daily intake for this age group and their estimated level of physical activity. In Study 1, the participants were found to be predominantly average maturing and past PHV but were still growing meaning it is even more important that energy intake is sufficient. Protein intake was within the recommended daily intake but was sub-optimally distributed across the day. Intake of carbohydrate was lower than recommended for the level of activity and there was no evidence that there was any greater intake at times when physical activity was high. Current advice for carbohydrate is to focus on fuelling for the work required. As identified in Study 2, hockey in this age group is a high intensity intermittent activity, and good ‘at the time’ energy availability will improve both performance and athlete wellbeing. Saturated fat and sugar intake were above the daily recommended intake and FV intake was low. Although this is common in studies in both the general population and other adolescent athletes this should be addressed to ensure good health outcomes outside of sports performance.

Self-report food diaries are easy to administer and are commonly used in athlete populations but can give poor insight into the context of when and how meals and snacks are eaten and how this relates to organised sport training or competition. The relationship between when and where meals are eaten, and the timing of activity or organised sports training will be examined in Study 4 and 5. The 4-day food and activity diaries used in the present study gave very strong detail on foods and drinks consumed but within the written records there was evidence that some meals were impacted by the timing of sports participation, for example supper being eaten late at night or early in the evening

and consisting of mostly snack foods. This may be affecting the energy value and quality of intake and also compromise sleep. It is also of particular interest to investigate how physical activity may be impacting carbohydrate and protein timing. Studies in adolescent athletes have found that hunger maybe increased after training (Rumbold *et al.*, 2013) but adult studies have found evidence that high energy foods may be rated as less palatable (Gustafson *et al.*, 2018) and that appetite suppressed after high intensity exercise (Crabtree, Chambers, Hardwick, & Blannin, 2014).

6. STUDY FOUR: Physical Activity and Nutrition Habits Survey in Female Adolescent Hockey Players.

6.1 Abstract

The purpose of this study was to document habitual eating behaviour and physical activity levels in female adolescent hockey players during the competitive season. **Methods**: Female adolescent hockey players (n=162, age 13.6 ± 2.0 yr) completed a questionnaire consisting of 30 questions split into four sections; general information about the players (Q1-9), physical activity (Q10-16), dietary intake (Q17-23) and sports specific nutrition and supplement use (Q24-30) covering behaviour in the previous 7-days. Three factor ANOVAs compared dependent variables for the level of hockey and if played at club and/or at school. Age, activity, and the ranked score for disrupted eating were compared using Pearson's correlations **Results**: Participants played 21 different sports in the previous 7-days including hockey, 17% played more than three sports at county level or above. PAQ-C summary score was 2.6 ± 0.7 indicating moderate activity. Participants were active in evenings (PAQ-C = 3.3 ± 1.1) and weekends (PAQ-C = 3.0 ± 0.9) but relatively sedentary in the morning (PAQ-C = 1.9 ± 0.9). Most participants ate breakfast (81%) and cooked lunch (74%), 23% ate a packed lunch at ≥ 4 times a week, 16% skipped lunch. Eating behaviour was impacted by sports participation, 28% eating their evening meal in a sports venue and those playing hockey at school and club showing greater disrupted eating patterns than participants who only played at club ($p<0.001$) or school ($p=0.02$). Most participants (95%) had ready meals or ate out ≥ 1 times a week. During sport 62% of participants reported that they did not eat during matches, 33% only drank water and 8% did not eat or drink. Sport related supplement use was uncommon (3%) but 25% of participants reported taking a multivitamin or mineral supplement. **Conclusion**: Self-report surveys of physical activity and eating behaviour provide vital information to understand the demands on adolescent hockey players. Players training and competing in more than one team or sport may struggle to maintain adequate nutritional intake.

6.2 Introduction

To design and implement a successful intervention to support female adolescent hockey players, it is important to develop a clear understanding of all their physical activity and nutritional habits. Nutrition is an important component of the support for adolescent athletes contributing to both their health and athletic performance. Adolescence is an age of increased growth and development, and careful consideration of nutrition needs is required to meet these demands (Desbrow*, et al.*, 2019; Hannon, Close*, et al.*, 2020; Hannon, Parker*, et al.*, 2020; Nascimento *et al.*, 2016). The energy requirements of adolescent athletes has been widely investigated (Carlsohn*, et al.*, 2011; Hannon, Parker*, et al.*, 2020) and have been found to be highly variable (Petrie*, et al.*, 2004). Differences in growth rates during the set chronological age bands of developmental teams, varying activity levels and training loads within the organised training sessions, differences in non-exercise activity thermogenesis (NEAT) and the presence of concurrent compensatory sedentary behaviours are all key factors influencing individual energy needs making them difficult to generalise (Burke, Melin*, et al.*, 2018; Desbrow*, et al.*, 2019; Petrie*, et al.*, 2004). LEA may be a particular concern for adolescent female athletes as they are more likely to be classified as 'highly specialised' than adolescent males and are more likely to participate in high competition volumes and play on multiple sports teams (Post, Bell*, et al.*, 2017) impacting their ability to match EE. Even sporadic low EI can result in training stagnation, poor skills development and greater fatigue (Wasserfurth*, et al.*, 2020). As low caloric intake may be unconscious, caused by lack of knowledge about the need for optimal EB, a lack of time to prepare meals, a high overall EE or the loss of appetite after training sessions (Heaney, O'connor, Naughton, & Gifford, 2008), it is important to be aware of all training and eating behaviour in this group.

Poor adherence to both National Dietary Guidelines and Sport Nutrition recommendations has been reported in young athletes (Gibson*, et al.*, 2011; Meyer*, et*

al., 2007; Rosen*, et al.*, 2017; Zalcman*, et al.*, 2007) and although increasing knowledge can be effective (Heaney*, et al.*, 2011), this has not been found to be the only factor when looking for effective behaviour change (Atkins and Michie, 2013; Bentley, Mitchell, & Backhouse, 2020). Athletes and coaches have reported time management around high training load and meal preparation as the main challenges faced in fuelling adequately (Logue et al 2021). The more that is known about an athlete's 'usual' behaviour the better the estimations of energy requirement and dietary intake can be, with fewer assumptions being made (Bentley*, et al.*, 2020).

The purpose of study 4 was to use an online physical activity and nutrition survey to document physical activity, sports participation, and dietary behaviour in a larger group of adolescent hockey players. The questions included, taken from three previously validated surveys in adolescent British school children giving a broader measure of behaviour (both physical activity and nutrition) in this group, giving context to the data collected in Studies 1-3. The aims of study 4 were to (1) identify the level of organised activity female adolescent hockey players were doing both during the school day and afterschool or weekends, (2) to discover more about eating behaviour in female adolescent hockey players and how this was impacted by sports training and (3) to learn more about the choices of food and drink that were being made around sports training and matches.

6.3 Methods

6.3.1 Study Design

This study was conducted in two parts:

1. Pilot Study - to investigate the feasibility of the Main Study, to reduce and focus the questions included, and to identify weaknesses in the online questionnaire.

2. Main Study - to document the physical activity, training volume and dietary behaviour of adolescent hockey players in England, with the aim of better understanding their dietary needs.

Ethics approval for the study was obtained from University of Chichester Research Ethics Committee

6.3.2 Participants

For the pilot study, participants were recruited through the Sussex and Hampshire Hockey Associations and included the participants who completed the physiological tests competed within Study 1 and dietary analysis in Study 3 of this thesis. Participants within the main study were contacted via emails to their club coaches and sent a link to the online survey, which were then filled in anonymously. All participants were female adolescent hockey players (age 13.6 ± 2.0) playing within their club or school age-group first teams and were regularly training and playing hockey in competitive leagues. Coaches were asked to only forward the survey link to players who had been put forward to the England Hockey Single System training, or whom they believed were of an equivalent level of ability.

6.3.3 Surveys

6.3.3.1 Pilot Study

Participants were asked to complete an online questionnaire (Online Surveys – previously BOS) during the 2015/16 hockey season and in the school term. A total of 24 adolescent female hockey players (13.8 ± 0.8 yr) completed the study which consisted of 25 questions, including questions taken from the PAQ-C physical activity survey (Kowalski*, et al.*, 1997), adapted for use in UK school children by Voss*, et al.* (2013) and Aggio*, et al.* (2016) and the ROOTs Dietary Questionnaire (Corder*, et al.*, 2011). As part of the pilot survey, each participant was also asked to list the types of foods and drinks

that were consumed before, during and after competition or training. The responses were used to construct the questions relating to food and drink consumption around competition and training within the Main Study. A copy of the Pilot Study questionnaire is given in Appendix A.

6.3.3.2 Main Study

A total of 148 competitive female adolescent hockey players (13.5 ± 2.2 yr) volunteered to complete an anonymous online questionnaire (Survey Monkey Version June 2, 2016. Monumentive Europe UC) in term time during the 2016/17 hockey season. Junior section head coaches at large hockey clubs, with active junior hockey teams were contacted through the email addresses listed on club websites and asked if they would circulate the online survey link to girls playing within age group teams (U12-U18) who were of the standard to be considered for the England Hockey Single System. All participants were given detail about the study before completion, informed about how they could contact the researcher if they wished to withdraw and provided informed consent. An answer was needed for every question for the survey to be completed. The questionnaire was composed of 30 questions aligned with questions from an adapted PAQ-C for the UK (Voss*, et al.*, 2013; Welk and Eklund, 2005) and the ROOTs Dietary Questionnaire (Corder*, et al.*, 2011). Additional questions were included on the level of hockey played, area of the country they played in and their eating behaviour during the school week, and around competition and training. The 30 questions were split into four sections.

Section 1 (Q1-9) general information about the players

Section 2 (Q10-16) physical activity (based on PAQ-C)

Section 3 (Q17-23) dietary intake (based on questions within ROOTs Survey)

Section 4 (Q24-30) sports specific nutrition and supplement use.

A copy of the Main Study questionnaire is given in Appendix B.

6.3.4 Data Collation and Calculations

From the Pilot Study, it was identified that the existing version of the online tool run by Bristol Surveys did not run effectively on mobile devices, and the Main Study was redesigned and relaunched on Survey Monkey. Feedback from the Pilot Study was also used to refine the questions asked. A high number of participants had stopped completing the survey at question 7 where they were asked in detail about sports participation, and this question was removed from the Main Study. Question 16 and 17 were combined as participants were found to have either trained immediately after school or later in the evening but not both. Questions 19 to 23 asked participants to list the foods and drinks that they had before, during and after matches and the given items were used to construct the choices within the Main Study. The list of drinks given were water, homemade and commercial sports isotonic drinks, coconut water, tea or coffee, milk and milk-based drinks, homemade and commercial recovery drinks, and fruit Juice. Foods listed were bananas, apple, orange, grapes, dried fruit, wholegrain bread and jam, sports gel, jelly sweets, fig rolls, malt loaf, chocolate biscuit, donuts, crisps, nuts, cheese, or a match tea. Additional questions were also added to the Main Study on eating behaviour, to discover more about the type and location of meals eaten; these questions were adapted from the questions on breakfast from the ROOTs Dietary Questionnaire (Corder*, et al.*, 2011).

A response rate could not be calculated as it was not possible to accurately identify the total number of hockey players who fitted the inclusion criteria or had the link sent to them. All the surveys were completed anonymously and only the date of birth was given. Participant ages were calculated as of the 1st of September in the year before they completed the survey. Ten students within the Main Study answered that they had been ill or injured in the previous week. Their answers were excluded from the results as the

answers given would not be representative of their normal activity or behaviour. All the participants in the Pilot Study reported that they had not been ill and had a normal week. A question on sex was included in the Main Study to ensure that all the responses recorded were female.

The PAQ-C was scored as detailed by Kowalski et al. (2004), using the version updated for English youth by Voss et al. (2013) and Aggio*, et al.* (2016) and the cut-off bands recommended by Kolimechkov*, et al.* (2017). Medium physical activity was assumed to have a PAQ-C summary value of >2.5 and <3.5 (Kolimechkov*, et al.*, 2017). Four of the questions in section three on dietary intake patterns were ranked using a Likert scale and the same scoring pattern as used in PAQ-C; the location and frequency of eating breakfast, the frequency of eating the evening meal in a car/bus or train and the number times lunch and dinner were skipped being used as a novel measure of disrupted eating.

6.3.5 Statistics

Data was analysed using JASP Team (2020) version 0.13.1. Dependent variables were calculated and summarised as the mean and standard deviation. Prior to analysis data was checked for normality using histograms and Shapiro-Wilk tests. Analysis of variance (ANOVA) tests were conducted to identify differences in PAQ-C scores and the novel measure of disordered eating across groups separated by where hockey was played and the level at which individuals played within the single system. Bonferroni's post hoc tests were used to identify the direction of any differences. Paired T-tests were used to investigate differences in PAQ-C score and ranked measures of eating behaviour by age. Statistical significance was accepted at $P<0.05$. Dependent variables for age, physical activity level and the ranked score for disrupted eating were compared using Pearson's correlations. In accordance with (Cohen) 1988 a correlation of

>0.5 was classified as large, 0.5-0.3 as moderate. 0.3-0.1 small and anything smaller than 0.1 as insubstantial (Cohen, 1988).

6.4 Results

6.4.1 Questionnaire Section 1: General Player Information

Of the 172 respondents to all surveys, 37% were from West Sussex, 20% from Hampshire and 10% from London. Responses were received from across the south of England specifically Avon, Dorset, East Sussex, Kent, Middlesex, Somerset, Surrey, Warwickshire, and Wiltshire. Five clubs in the north of England were contacted, but no participants recorded that they played in these counties. A total of 76% of respondents across both studies recorded that hockey was their main sport and 37% of that their goal was to play hockey for Great Britain. 63% said they played at least two other sports competitively. All were resident in, and in full time education within the UK and were of equivalent age and playing experience.

Figure 6.1 shows the distribution of sport participation given within the Pilot Study. This question from the PAQ-C was later removed from the Main Study to make the questionnaire more manageable and ensure higher completion rates. Participants within the Pilot Study were also asked to record their main sport, if not hockey, and the level at which they played. Of those that said hockey was not their main sport, netball, football, cricket, judo, trampolining, swimming, and athletics were given. Swimming, trampolining, netball, football, and athletics were played at county level or higher and 17% of participants were competing in three sports at county level or above.

Figure 6.1 Sports participation within the Pilot Study. Number of times each sport is played a week. Sports selected taken from PAQ-C adapted for participants within the UK. No participants recorded participating in rowing, skating, sailing, skiing or ultimate frisbee in the previous 7-days.

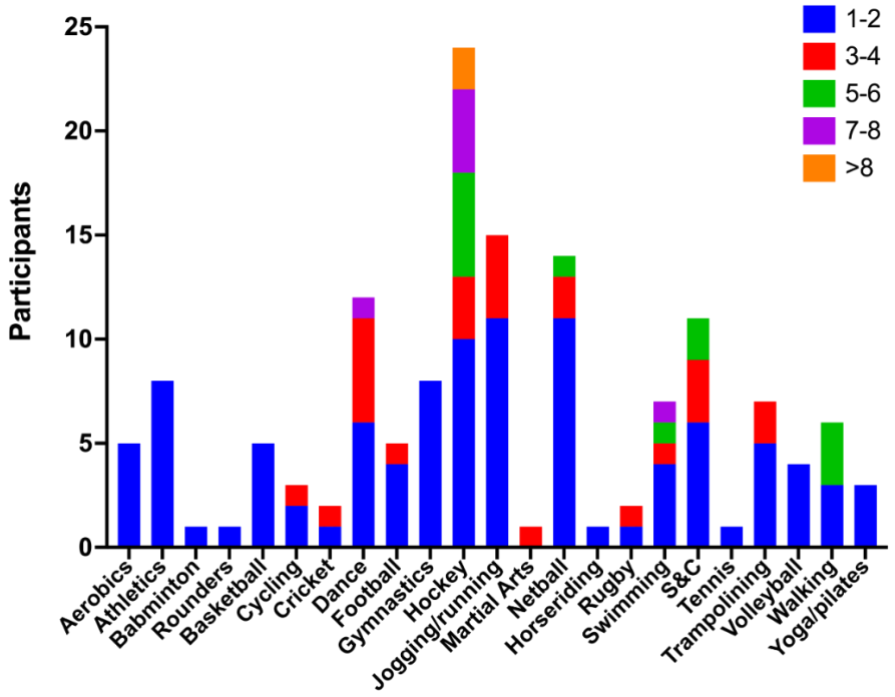
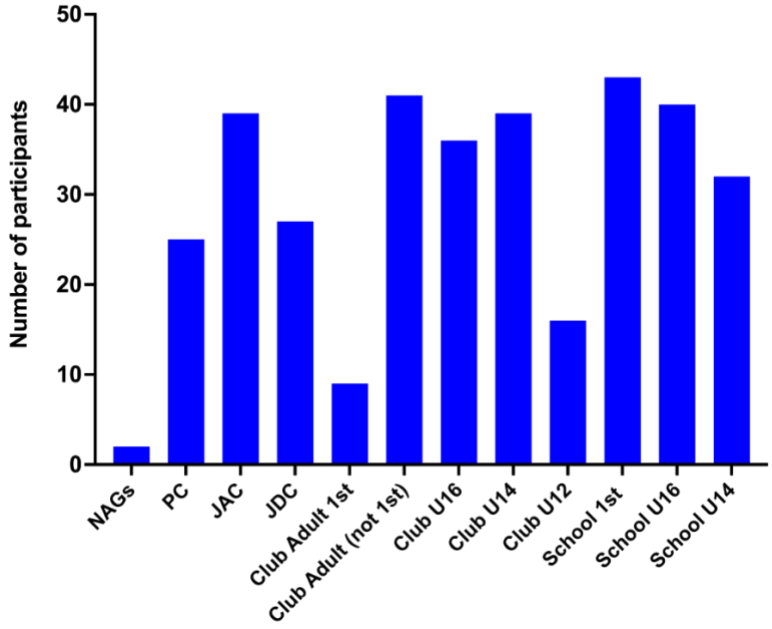


Figure 6.2 shows the distribution of the teams that the participants had played for within the current season. A total of 42 % of participants played for more than one hockey team (1.58 ± 0.82) and 28% played for both club and school teams. Three percent of participants had been selected to train in National Age Group Squads, 14% at Performance Centres, 17% at Junior Academy Centres and 13% at Junior Development Centres. All players selected for the National Age Group Squads played at both school and within the club system. Of the participants who had been selected to train at Performance Centres, 48% played only within the club system, 22% only at school and 26% at club and school.

Figure 6.2 Number of participants who recorded playing within each squad or team within the current season. Clubs and schools can put forward players to the Junior Development Centres (JDC) and from there players can be selected for each of the higher training groups (National Age Group (NAGs), Performance Centre (PC) and Junior Academy (JAC)) consecutively.



6.4.2 Questionnaire Section 2: Physical Activity

Although the participants across both studies were one homogenous group of age matched adolescent female hockey players, Pilot Study participants were playing a greater number of hours than those in the Main Study ($p=0.001$) and there were differences in the proportion of players selected to play at the different England Hockey Centres, 54% of players within the Pilot Study being selected for Performance or Academy Centre Training (NAGs, PC & JAC) versus just 24% within the main study. 16% of all participants attended schools which had lessons on a Saturday; 1 within the Pilot Study and 25 in the Main Study. The total PAQ-C summary score decreased with age ($r=-0.4$, $p<0.001$)

Table 6.1 shows the physical activity scores for the main and pilot studies. Although the participants were matched for age, Pilot Study participants recorded playing a greater number of hours than those in the those in the Main Study ($p=0.001$), had a higher PAQ-C score for hours played and attended a greater number of organised sports sessions ($p=0.002$). No other differences in activity level were seen.

Table 6.2 shows the physical activity scores separated by the type of team that the participants recorded that they played for. Participants that only played for a school team were younger than those that played for both club and school ($p=0.007$). Players who played at club and school did more hours of organised sport than those who only played for clubs ($p=0.003$) but there was no difference in the number of sessions recorded. Players who recorded only playing at school ($p<0.001$), or both club and school ($p=0.03$) were recorded as more active before school than participants who only played for a club. Players who only played at school were also more active at lunch break ($p=0.02$) than club players. After school players who recorded playing for both club and school were the most active (club $p<0.001$, school $p=0.004$).

Table 6.3 shows the physical activity scores separated by level of hockey the participants recorded playing at within the England Hockey Single System. Players were split between those who had been selected to attend a Performance Centre, or National Age Group training (performance), players who attended Junior Academy Centres (academy) and those who were not playing within the single system, which included players who had attended Junior Development Centres but had not moved on to the academy in the current year. Participants selected to be in Performance Groups were more active at lunchtime ($p=0.01$) and Academy players were more active after school than both Performance Group players ($p=0.02$) and unselected players ($p=0.003$). There were no other differences between these groups.

Table 6.1 PAQ-C score, results for each individual PAQ question and the percentage of female hockey players who recorded playing in each timeframe. For the PAQ-C scores each item was scored between one and five in order of activity intensity in line with scoring by Kowanski *et al* 2004. Data expressed as a mean ± standard deviation. Difference between the Pilot and Main Study is expressed by *p < 0.05, ** p < 0.01, *** p < 0.001.

	TOTAL	Pilot Study n=24	Main Study n=138
Age (years)	13.6 ± 2.0	13.7 ± 0.8	13.5 ± 2.2
PAQ-C Score Hours	2.9 ±1.2	3.5*** ±1.2	2.8*** ± 1.2
Number of hours of organised sport played a week	8.9 ± 3.4	11.1*** ± 3.1	8.6*** ± 3.3
Number of organised sport sessions a week	8.9 ± 4.0	11.3** ± 4.2	8.5** ± 3.8
PAQ-C Score for before school	1.7 ± 1.0	1.5 ± 0.7	1.9 ± 1.1
Percentage doing organised sport before school at least once a week.	48	38	50
PAQ-C Score for morning break	2.0 ± 1.2	1.7 ± 0.9	2.1 ± 1.2
Percentage organised sport in morning break at least once a week.	53	46	55
PAQ-C Score for Lunch break	2.6 ± 1.6	2.7 ± 1.7	2.6 ± 1.6
Percentage doing organised sport in lunch break at least once a week.	61	67	66
PAQ-C Score for After School	3.3 ± 1.1	3.4 ± 1.1	3.3 ± 1.1
Percentage doing organised sport after school at least once a week.	96%	96%	96%
PAQ-C Score for Weekend activity	3.0 ± 0.9	3.3 ± 0.9	3.0 ± 1.0
Percentage doing organised sport at least once at the weekend.	98%	100%	97%

Table 6.2 PAQ-C score and values for each individual PAQ question in female adolescent hockey players split by where individuals play hockey (club, school or both club and school). For the PAQ-C scores each item was scored between one and five in order of activity intensity in line with scoring by Kowanski *et al* 2004. Data expressed as a mean ± standard deviation. Differences between playing for club, school and both club and school are expressed by * p < 0.05, ** p < 0.01, *** p < 0.001.

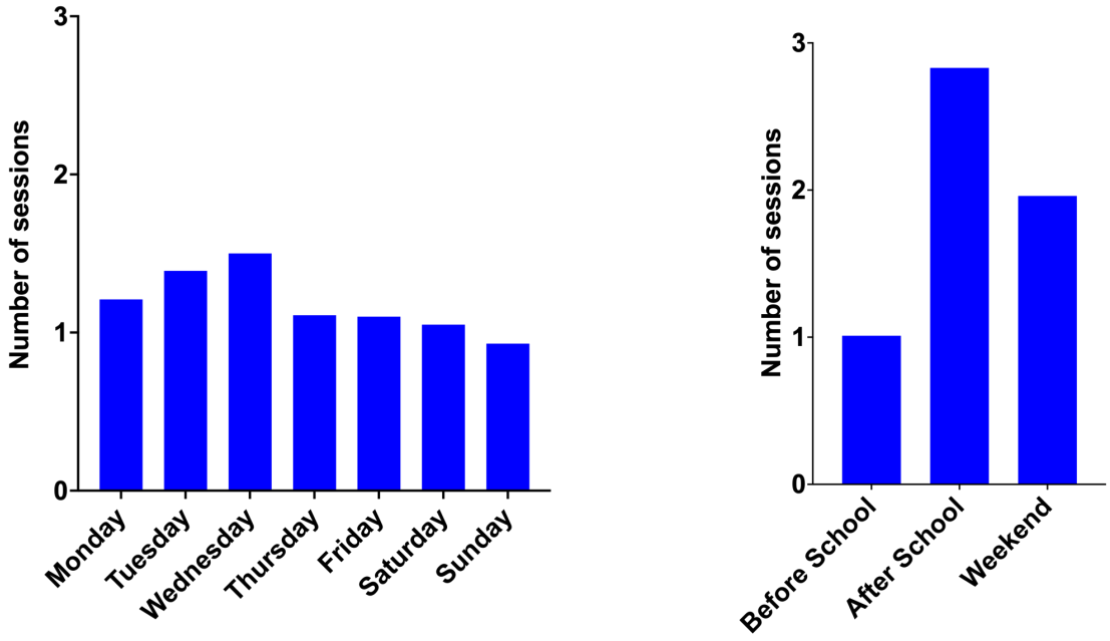
	Club only n=78	School only n=35	Both club and school n=49
Age (years)	13.4 ± 2.2	12.9** ± 1.6	14.2** ± 1.8
Number of hours of organised sport played over the previous week	8.3** ± 3.4	8.4 ± 3.1	10.3** ± 3.1
Range of hours played over the previous week	4-16	3-17	5-15
PAQ-C hours played	2.8 ± 1.3	2.7 ± 0.99	3.2 ± 1.1
Number of organised sport sessions a week	9.7 ± 3.7	8.3 ± 3.2	9.7 ± 3.7
PAQ-C sessions attended	2.8 ± 1.3	2.7 ± 1.0	3.2 ± 1.1
PAC-Q Score for before school	1.6***,* ± 0.9	2.4*** ± 1.4	2.1* ± 1.2
PAQ-C Score for morning break	1.9 ± 1.1	2.3 ± 1.4	1.9 ±1.1
PAQ-C Score for Lunch break	2.3* ± 1.6	3.3* ± 1.7	2.6 ± 1.6
PAQ-C Score for After School	2.1**,*** ± 1.2	2.9** ± 1.4	3.0*** ± 1.5
PAQ-C Score for Weekend activity	2.9 ± 1.0	3.1 ± 1.0	3.28 ± 1.0
PAQ-C Score Week summary	2.3**,** ± 0.7	2.8** ± 0.6	2.8** ± 0.8

Table 6.3 PAQ-C score and values for each individual PAQ question in female adolescent hockey players split by level of play (NAGs/PC, JAC or not selected above JDC). For the PAQ-C scores each item was scored between one and five in order of activity intensity in line with scoring by Kowanski *et al* 2004. Data expressed as a mean ± standard deviation. Differences between Performance, Academy and those not selected are expressed by * p < 0.05, ** p < 0.01, *** p < 0.001.

	Performance n=24	Academy n=28	Not Selected N=110
Age	13.8 ± 1.8	13.7 ± 1.4	13.5 ± 12.2
Hours of organised sport played previous 7days	9.8 ± 2.5	10.4 ± 3.9	8.4 ± 3.3
Range of hours played over the previous week	5-14	3-16	3-17
PAQ-C hours played	3.4 ± 0.8	3.3 ± 1.3	2.7 ± 1.2
Number of organised sport sessions a week	10.2 ± 2.6	10.2 ± 4.8	8.2 ± 3.9
PAQ-C sessions attended	3.4 ± 0.8	3.3 ± 1.3	2.7 ± 1.2
PAC-Q Score for before school	1.8 ± 1.0	2.0 ± 1.1	1.9 ± 1.1
PAQ-C Score for morning break	2.0 ± 1.2	1.9 ± 1.0	2.0 ±1.2
PAQ-C Score for Lunch break	3.5 * ± 1.8	2.4 ± 1.5	2.5 * ± 1.6
PAQ-C Score for After School	2.3* ± 1.4	3.4*,** ± 1.4	2.4** ± 1.4
PAQ-C Score for Weekend activity	3.4 ± 1.0	3.1 ± 0.8	3.0 ± 1.1
PAQ-C Score Week summary	2.8 ± 0.6	2.8 ± 0.8	2.4 ± 0.7

Figure 6.3 shows the distribution and timing of sessions played across the week. The greatest frequency of participation in organised sport was after school and at the weekends. The most active day school day reported was Wednesday.

Figure 6.3 Distribution of sports sessions and the timing of sessions over the previous 7-days in female adolescent hockey players. Data expressed as mean values. The mean activity level across the week was 1.1 (± 0.2) sessions a day.

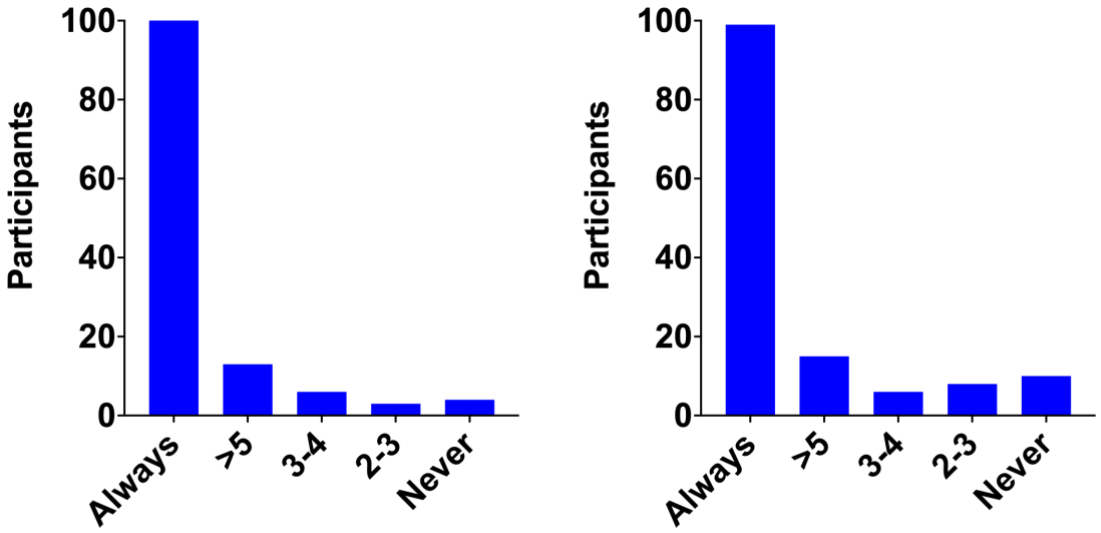


6.4.3 Questionnaire Section 3: Dietary Intake

Participants were asked about their eating behaviour, and where they ate their meals in the seven-days before they filled in the questionnaire. Figure 6.4 shows how often the participants in the Main Study ate breakfast (6.4a), how often this was eaten at home (6.4b), where else breakfast was eaten (6.4c) and at what time participants preferred to eat breakfast when given the choice (6.4d). A total of 81% of participants reported always eating breakfast in the last week and 72% said that they always had breakfast at home.

Figure 6.4 Results of the dietary behaviour questions on breakfast eating habits included in the questionnaire given to adolescent hockey players.

6.4a – Number of days breakfast is eaten. **6.4b – Days eaten at home.**



6.4c – Where breakfast is commonly eaten. **6.4d – Preferred time.**

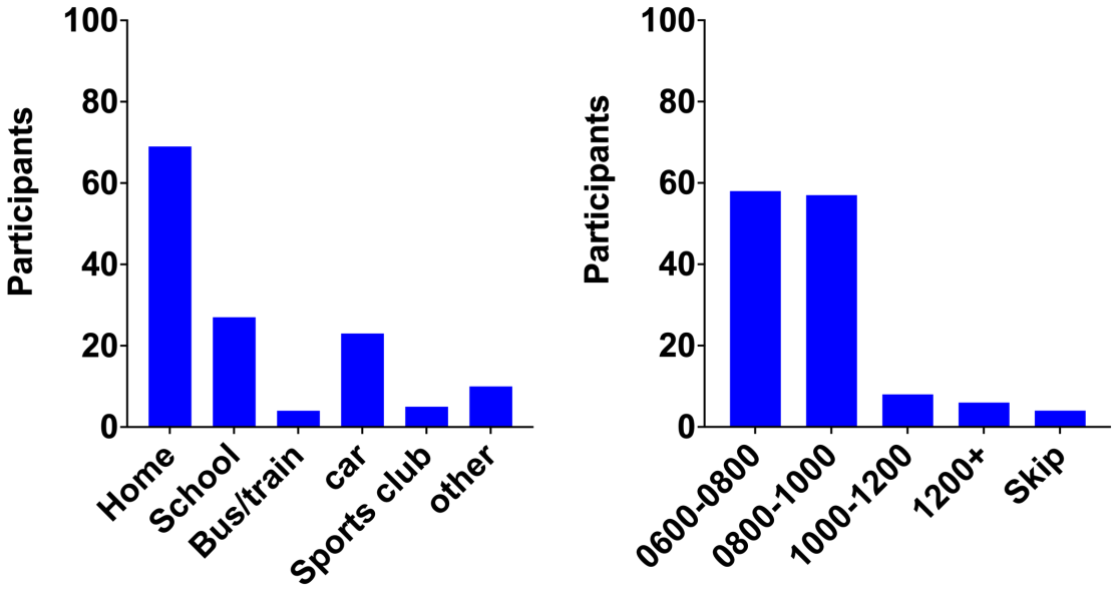


Figure 6.5 shows the responses to the questions on lunchtime eating behaviour. A total of 74% of participants recorded that they ate a cooked lunch in the school dining room

at least four times a week. A total of 23% of participants had a packed lunch either prepared at home or by the school at least four times a week and 16% of participants skipped lunch at least once a week.

Figure 6.5 Lunchtime eating habits over the last seven days in the Main Study. Options given were eating a cooked lunch in the dining room (Dining room), a packed lunch made at home (Home packed), a packed lunch made by school (School packed), lunch bought from the school tuck shop or vending machine (Vending), lunch bought outside school (Ate Out) and skipping lunch (Skip).

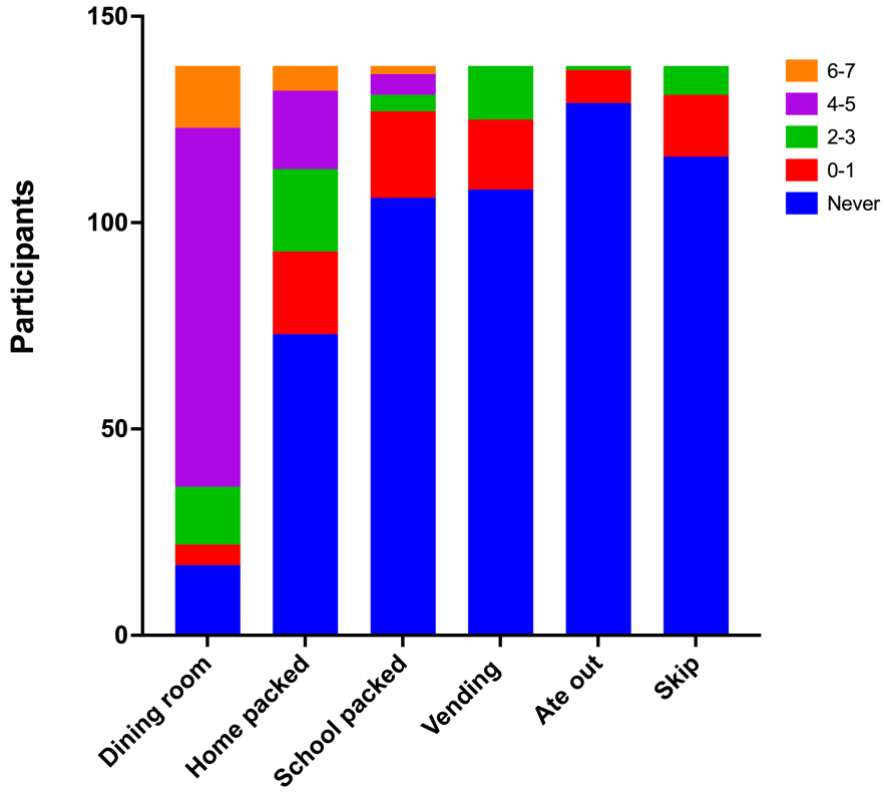
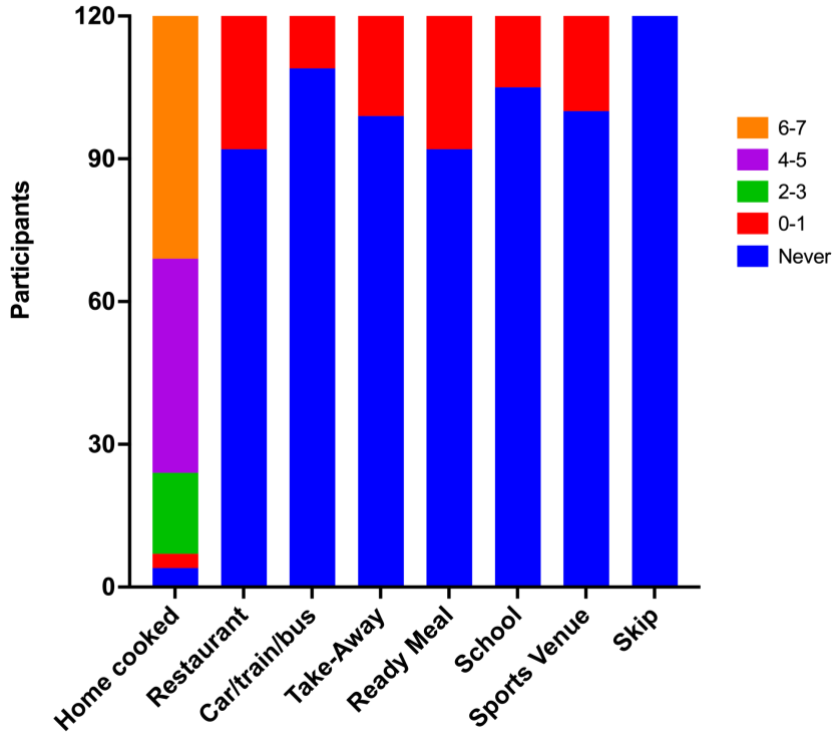


Figure 6.6 shows the results for the questions asked about eating behaviour in the evening. A total of 83% of participants recorded that they ate a meal that was prepared, cooked and eaten at home at least four times a week but 95% of responses recorded

that they ate in a restaurant, had a take away or ready meal at least once a week. In total 28% of participants ate their evening meal in a sports venue at least once a week.

Figure 6.6 Evening meal eating habits in the Main Study. Options given were a meal prepared, cooked, and eaten at home, a meal that was eaten at a restaurant or café, a takeaway meal eaten at home, a meal at home that was readymade and just reheated, having your evening meal at school, having your evening meal at a sports venue, or missing your evening meal.



In order to understand whether sports participation had an influence on eating behaviour, the location and frequency of eating breakfast, the number of times lunch and dinner were skipped and the number of evening meals eaten whilst travelling were ranked and used to create a novel measure of eating disruption (Table 6.4). Playing at both a school and club level increased this measure of disrupted eating in comparison to playing only for a club ($p<0.001$) or only at school ($p=0.02$). The level of hockey played did not

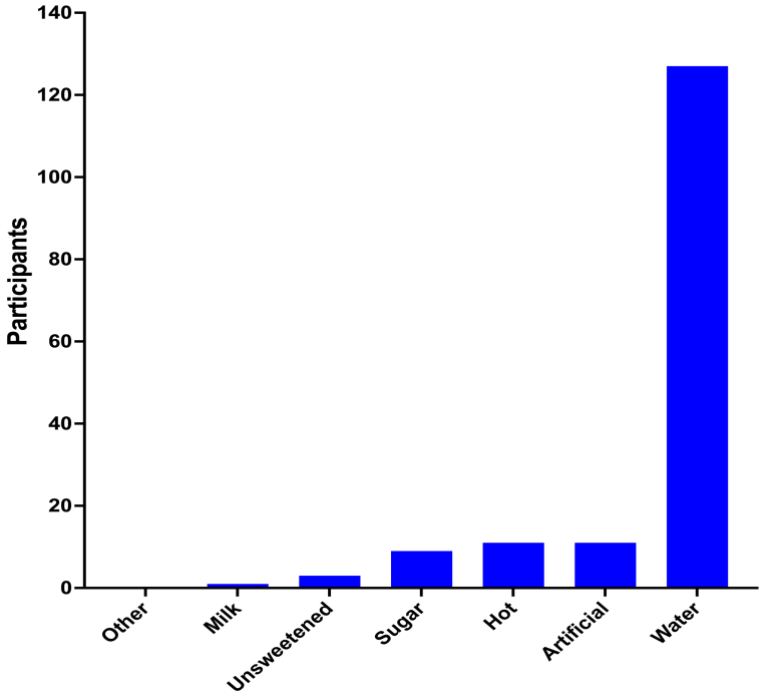
influence this index. The likelihood of disrupted eating increased with age (r=0.20, p=0.012).

Table 6.4 Measure of disrupted eating calculated from the answers to the questionnaire questions on eating frequency and location split by teams that the participants play for and the level of hockey. * p < 0.05, ** p < 0.01, *** p < 0.001.

	TOTAL	Club only	School only	Both club & school	Performance	Academy	Not selected
	n=162	n=78	n=35	n=49	n=24	n=28	n=110
Measure of disrupted eating	4.6 ±0.4	4.7*** ±0.4	4.7* ±0.4	4.2***,* ±0.5	4.6 ±0.4	4.6 ±0.5	4.6 0.4

Figure 6.7 shows the types of drinks chosen when participants were thirsty between meals. The main drink of choice of water, reported by 92% of participants as their first choice. In a second question asking about the type of water they would choose 64% chose tap water, 38% chose filtered tap water, 13% bottled still water and 3% sparkling water.

Figure 6.7 Drink choice when thirsty over the previous seven days in adolescent female hockey players. Options given were water (tap, bottled, still or sparking), artificially sweetened drinks (diet cola, diet lemonade, sugar free squash, sugar sweetened drinks (cola, lemonade, squash, sunny delight), unsweetened pure fruit juice, hot drinks (tea or coffee), milk drinks (milk, milkshake, hot chocolate) or other options could be given.



6.4.4 Questionnaire Section 4: Sport specific nutrition

Figure 6.8 shows the types of drinks that were recorded as being drunk before, during and after a match. Water was the most popular drink during matches; 88% of participant drank water in the hour before a match, 92% drank water during a match and 88% after a match. Bought and homemade sports drinks were also used before, during and after games and bought and homemade recovery drinks were used by 21% of participants.

Figure 6.8 Drinks chosen by adolescent female hockey players in the Main Study usually drunk before, during and after a match. The options were water, a commercial sports drink (bought sport), a homemade sports drink (homemade sport), a smoothie, hot or caffeinated drinks like tea & coffee (hot caffeinated), milk-based drinks, a commercial recovery drink (bought recovery) or a homemade recovery drink. Coconut water was also given as an option but was not selected by any participants.

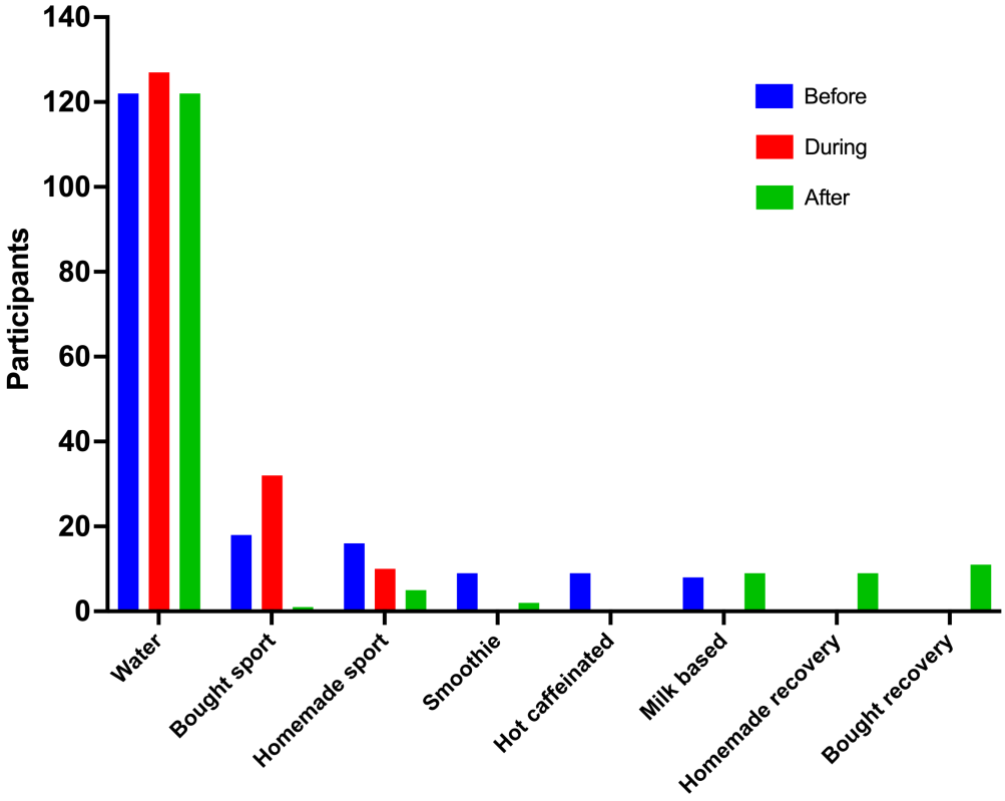


Figure 6.9 shows the frequency foods were recorded as eaten before a match. Bananas were the most popular food eaten, being chosen by 44% of participants as something that they would eat before sport. A total of 22% of participants choose high glycaemic index carbohydrates (CHO gel, Jelly sweets, white-bread, and jam) and 12% of participants chose high fat foods (nuts, crisps, cheese, chocolate biscuits).

Figure 6.9 Foods chosen by adolescent female hockey players in the Main Study that they usually eat before a match.

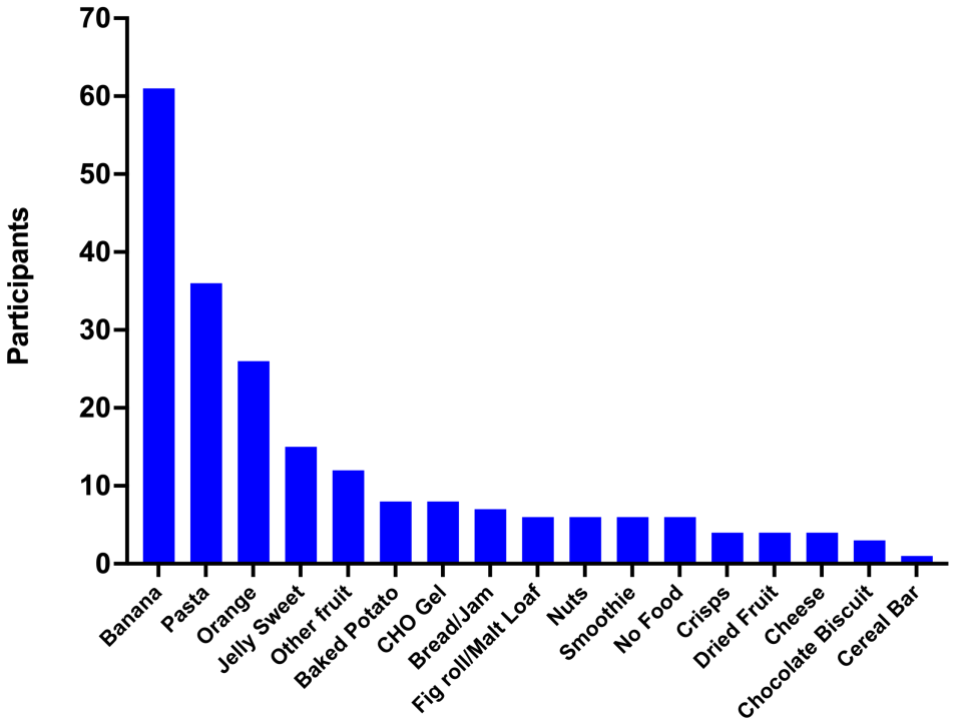


Figure 6.10 shows the frequency selected foods were eaten during matches or at half time. The most popular option chosen was jelly sweets (22%) and a further 4% had carbohydrate energy gels. 27% of participants chose fruit (banana, orange, or other fruit). Over half of respondents (62%) said that they did not eat during matches. Figure 6.11 shows the frequency selected foods were eaten after hockey matches. 39% of players reported that they usually have a match tea after games, 22% chose fruit and 9% pasta. Chocolate biscuits (15%) and crisps (13%) were also popular choices.

Participants in all studies were asked about supplement use. A total of 25% of participants recorded that they took a vitamin or mineral supplement with the most common taken being multivitamins, Vitamin C, Vitamin D, Calcium, and Iron. Only 3% of respondents said that they took a sports supplement, all these said that they took protein supplements, and one also took creatine.

Figure 6.10 Foods chosen by female adolescent hockey players in the Main Study that they usually eat during a match.

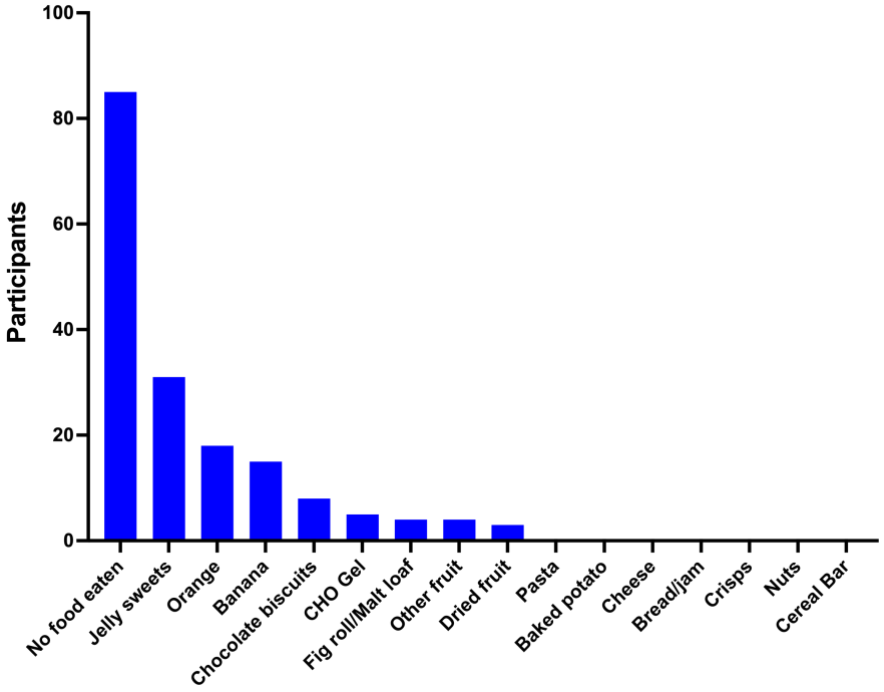
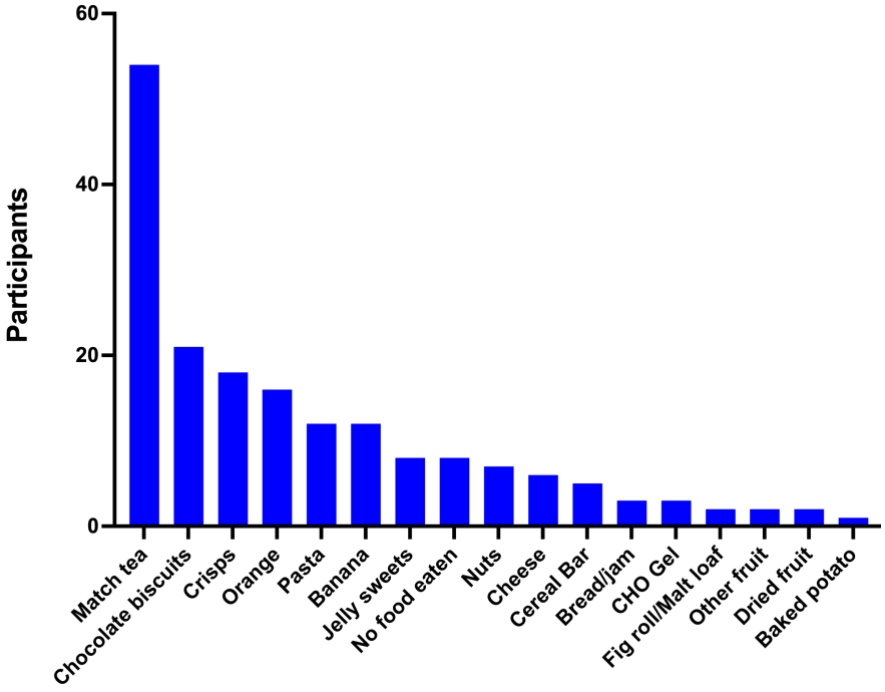


Figure 6.11 Foods chosen by adolescent female hockey players in the Main Study that they usually eat after a match.



6.5 Discussion

The present study is the first to examine in-season, term-time physical activity and eating behaviour in female adolescent hockey players. The study has resulted in an increased understanding of the timing of nutritional intake, the types of foods and drinks eaten, and the timing and volume of physical activity and training.

6.5.1 Section 1: General Player Information

All participants within the study were active female adolescent hockey players, playing for top school or club teams. Although this could not be confirmed it was believed that all participants would be classed as tier 2 or 3 (Mckay*, et al.*, 2022). In the Pilot Survey, participants recorded taking part in 21 other sports or types of physical activity over the previous 7-days including hockey training. Although playing competitively, only 76% of all participants recorded hockey as their main sport. A wide participation in sport is known to be positive for sports development, previous studies concluding that team sport athletes should participate in multiple sports into late adolescence, as this forms better tactical awareness and gives measurable competitive advantage (Bridge and Toms, 2013). Early specialisation in just one sport has negative consequences on athlete development (Sagas, 2013), increases the chances that a young athlete is injured or drops out from sport (Difiori *et al.*, 2014; Jayanthi and Dugas, 2017; Sagas, 2013) and this is known to be particularly detrimental for female athletes (Post, Trigsted*, et al.*, 2017). The identified wide participation in sport was seen as beneficial for the participants in the present study but highlights the need to take all activity into account when looking at the nutritional adequacy in this group.

6.5.2 Section 2: Physical Activity

In young athletes, physical activity EE is often the greatest contributor to TEE (Hannon, Parker*, et al.*, 2020; Silva *et al.*, 2013) and can vary considerably both between

individuals playing the same sport and for the same individual between days (Hannon, Close*, et al.*, 2020). To allow consistent energy to be available for growth and maturation, as well as optimising nutrient availability for sport development; training adaptation, recovery, and performance, it is important to understand not only the EE related to sport, but also know how this fits in with the individual's general activity profile.

There are no published studies on physical activity in adolescent hockey players or that have investigated how organised training influences total physical activity over a week. Available studies on nutritional adequacy in female team sport athletes either estimated the athletes level of activity between measured training sessions (Gibson*, et al.*, 2011), use self-report physical activity diaries (Baker*, et al.*, 2013; Beals, 2002) or rely on predictive equations based on likely activity (Mullinix*, et al.*, 2003; Papadopoulou*, et al.*, 2002; Parnell*, et al.*, 2016). Self-report questionnaires are not recommended for use in children because of difficulty in correctly interpreting questions and accurately recalling the duration or intensity of activity (Janz*, et al.*, 2008). Activity during childhood and adolescence is often varied and sporadic (Hussey, Bell, & Gormley, 2007) and so activity questionnaires that reduce the need for long term recall or estimation skills are more effective (Kremers, Visscher, Seidell, Van Mechelen, & Brug, 2005). The PAQ-C is a well-recognised validated activity questionnaire and has been widely used to assess term time activity during adolescence (Aggio*, et al.*, 2016; Benítez-Porres*, et al.*, 2016; Hidding*, et al.*, 2018; Janz*, et al.*, 2008; Kowalski*, et al.*, 2004; Marasso*, et al.*, 2021; Montgomery*, et al.*, 2021; Stewart and Lim, 2017; Thomas and Upton, 2014). The original PAQ-C has been modified and validated for secondary school children in the UK by adapting the sports included (Montgomery*, et al.*, 2021; Stewart and Lim, 2017; Voss*, et al.*, 2013; Welk and Eklund, 2005) and including sections on morning break and before school activity (Aggio*, et al.*, 2016).

In the present study, the PAQ-C summary score for the seven measures taken was 2.6 ± 0.7, in line with the values for similarly aged general populations of English adolescent girls (not specifically sports performers) by; Montgomery*, et al.* (2021), 2.5 ± 0.6 at 14.4 yr, Stewart and Lim (2017), 2.7 ± 0.6 at 12-17 yr, and Voss*, et al.* (2013), 2.6 ± 0.6 at 13-13.9 yr. This summary score classifies participants in the present study as moderately active (Kolimechkov*, et al.*, 2017). However, only seven of the nine measures from the survey were used compared to all nine used by Montgomery*, et al.* (2021), Stewart and Lim (2017) and Voss*, et al.* (2013). This is likely to have resulted in an underestimation of total activity, as the question not included in the present study on activity done in school PE lessons is high scoring, and because hockey has a relatively high intensity profile when compared to other sports played. Comparison with the breakdown of PAQ-C scores for the individual questions in Voss*, et al.* (2013) and for younger children (8.7 yr) by Kolimechkov*, et al.* (2017), suggests that the values in the present study for lunchtime, evening and weekend activity were higher than previously found in English school children and were more similar to the values in the same studies given for boys (Kolimechkov*, et al.*, 2017; Voss*, et al.*, 2013). Physical activity in the present study for morning and break-time activity were lower than the activity levels found in the school-based studies, which may reflect similar findings in athletes that have shown greater volumes of sedentary behaviour outside sport training, when compared to matched controls (Exel *et al.*, 2018; Sperlich *et al.*, 2017; Weiler*, et al.*, 2015). The six options given for activity within the PAQ-C for morning break and lunch break were; sat down talking, reading or doing school work, music lesson or practice, stood around or walked around, played with my friends, ran around or played sport some of the time or ran around and played sport all of the time (Kowalski*, et al.*, 2004). In the present study, combining lunch and morning break, 43% of total break-time activity was given as sitting, and a further 23% as standing around. Although 14% of activity was given as 'ran around or play sport all of the time', most activity during the school day was low intensity. PAQ-C values for evening (2.5 ± 1.4) and weekend activity (3.1 ± 1.0), at times when organised

sports training is commonly held, are high in the present study (Kolimechkov*, et al.*, 2017; Montgomery*, et al.*, 2021; Voss*, et al.*, 2013).

Although participants in the present study were taking part in a wide variety of sports, they only recorded doing 8.9 ± 3.4 hours of activity in the previous seven days, a mean daily activity of 1.1 ± 0.2 hours, a total which did include school sports lessons, as well as outside school clubs and training. The current guidelines from the Chief Medical Officer in the UK is that children and young people should take part in organised sport or physical activity of moderate to vigorous intensity (MVPA), for an average of 60 minutes a day (Sport England, 2021), only just below the average amount given in the present study. Furthermore, although the amount of MVPA increases with the number of sports sessions participated in, studies show that only between one third and one half of adolescent team sports training time is spent in MVPA (Leek *et al.*, 2011; Ridley, Zabeen, & Lunnay, 2018) with the remaining training time spent in sedentary or light intensity physical activity. Koorts *et al.* (2019) measuring MVPA in Australian adolescents (15.3 ± 1.5 yr) found that every extra sport participated in was only worth an additional 5 minutes a day of MVPA. Within the present study, participants who only played club hockey did fewer hours of activity than players who played for both club and school teams but there was no difference in the mean hours of sport done when the participants were split by the level of hockey they played. However, it was not possible to tell whether the training attended for higher teams, was at a different intensity. It is likely that there were considerable differences in training load between junior training and the adult training sessions attended by the 31% of participants who played in adult teams, which was not reflected in the hours played. Participants who played only for a school team were younger than those that played for both club and school. Many players will learn to play at school and will only start to play at a club as their interest in the sport increases, which would explain this difference.

Within the present study, there was a wide range of reported activity levels, from just 3 hours in the previous 7 days, to 17 hours and this wide variety may mask the full energy cost of training and hide the fact that some participants recorded that they were doing higher than recommended training volumes (LaPrade et al 2016, Biese et al 2020), and up to 20 sessions a week. It is recommended that young players do not do more hours of training than their age in years (LaPrade et al 2016, Biese et al 2020) and should have at least one day off a week (Jayanthi, Labella, Fischer, Pasulka, & Dugas, 2015).

6.5.3 Section 3: Dietary Intake

Food diaries are the most common method of collecting information about athletes dietary intake, however studies in children and adolescents have shown considerable misreporting of foods eaten; both reporting foods that were not eaten and underreporting intake (Forrestal, 2011). Understanding more about the timing of meals, how they are cooked and where they are eaten can add key detail to allow better understanding of how adolescent athletes are eating and how this is influenced by their sport. Time constraints associated with training or competition can make achieving an adequate and balanced diet more difficult (Smith, Holmes, & Mcallister, 2015) and availability of correct choices and knowledge of the current guidance are key factors influencing food intake (Bentley*, et al.*, 2020; Birkenhead and Slater, 2015). Availability or accessibility of foods are powerful predictors of consumption in adolescents with greater availability being related to greater intake (Cook, O'reilly, Derosa, Rohrbach, & Spruijt-Metz, 2015).

Children who eat breakfast regularly have better nutritional profiles than those who miss breakfast (Rampersaud, Pereira, Girard, Adams, & Metzl, 2005). In the present study, 81% of participants reported always eating breakfast in the last week and 72% said that they always had breakfast at home. Previous studies have found that physically active adolescents are more likely to eat breakfast than inactive adolescents (Corder*, et al.*,

2011) but are more likely to miss breakfast than any other meal, (Dwyer *et al.*, 2001; Nicklas, Reger, Myers, & O' 'Neil, 2000). The number of children who miss breakfast increases through adolescence (Lytle, Seifert, Greenstein, & Mcgovern, 2000; Nicklas *et al.*, 2004) with more girls skipping breakfast than boys (Nicklas*, et al.*, 2004). In the present study, only 3% of participants never ate breakfast, which is lower than seen in previous studies, the UK's Change4Life campaign found 15-25% of British adolescents (11-18 yr) regularly skip breakfast, and the National Diet and Nutrition Survey (NDNS) found 19% of adolescents (13-18 yr) were irregular breakfast consumers and 4% were non-breakfast eaters (NDNS, 2018). Eating breakfast (Corder*, et al.*, 2011) and increasing EI at breakfast (Briggs *et al.*, 2017) have both been associated with higher physical activity during the day (Briggs*, et al.*, 2017; Corder*, et al.*, 2011; Pollitt and Mathews, 1998) and higher MVPA at the weekends (Corder*, et al.*, 2013).

Adolescence is the time at which individuals begin to have greater independence from the family in choosing what they eat (Thomas, 1991). Consequently, adolescents tend to snack and graze, miss meals, eat away from home, and consume fast foods more frequently than younger children or adults (Mckinley*, et al.*, 1995; Squire, 2013; Story*, et al.*, 2002). Higher consumption of fast or snack foods is particularly common (French, Story, Neumark-Sztainer, Fulkerson, & Hannan, 2001; Thomas, Nelson, Harwood, & Neumark-Sztainer, 2012) and results in adolescents eating more high fat, high sugar foods as meal replacements (Squire, 2013). In the present study, 70% of participants ate a packed lunch at least once over the last week and 23% of participants ate a packed lunch at least 5 times. There has been little research specifically in adolescents but studies in younger children have found that the most popular foods consumed by children having a packed lunch at school are high in sugar, highly processed and lack B-vitamins, protein and fibre (Arcan *et al.*, 2007; Summerbell, Moody, Shanks, Stock, & Geissler, 1995). The questions in the present study did not distinguish between packed lunches eaten at school or at the weekend but 6% of participants had a packed lunch 6-7 times

a week and 23% of participants had pack lunches provided by the school, which are commonly provided when individuals are required to miss lunch due to travelling to or preparing for sporting fixtures.

In the present study 74% of participants recorded that they ate a cooked lunch in the school dining room and 28% of participants ate their evening meal in a sports venue at least once a week. Although school meals have been found to be higher in nutrients than packed lunches (Arcan*, et al.*, 2007; Summerbell*, et al.*, 1995), sport venues and school or college canteens frequently offer easy access to high energy, low nutrient foods, snacks and beverages (Naylor, Olstad, & Therrien, 2015) which is likely to promote increased intake of high energy low nutrient foods (Cook*, et al.*, 2015). A total of 95% of participants also recorded that they ate in a restaurant, had a takeaway or ready meal at least once in the previous 7-days.

EA and nutritional intake should be closely monitored during adolescence as it is a time when an individual's relationship with diet and body image are formed (Craigie, Lake, Kelly, Adamson, & Mathers, 2011) and the risk of developing an eating disorder is at its highest (Pettersen, Hernæs, & Skårderud, 2016). Increases in early sport-specific training can create instances where pubertal changes can be perceived as negative for performance (Bratland-Sanda and Sundgot-Borgen, 2013), particularly where there is an increased chance of choosing a sport inappropriate for the athlete's body type (Sundgot-Borgen and Torstveit, 2004). Although dieting is common in adolescence (Arcan*, et al.*, 2007; Martinsen*, et al.*, 2010), adolescent athletes with high energy requirements are more vulnerable to the physical and psychological consequences of this behaviour (Desbrow*, et al.*, 2014). Pressure from coaches, family and team mates to perform can have a negative impact on lifelong relationships with food and body image (Desbrow*, et al.*, 2014). It is common for female athletes to be looking to lose weight (Joy, Kussman, & Nattiv, 2016; Martinsen*, et al.*, 2010; Parnell*, et al.*, 2016) but insufficient caloric intake

in young athletes can also occur unintentionally when adolescents transition to higher levels of competition and the number of weekly training hours increase disrupting the timing of meals (De Souza*, et al.*, 2014). In the present study a novel, unvalidated measure of disrupted eating was calculated by ranking the location and frequency of eating breakfast, the number of times lunch and dinner were skipped and the number of evening meals eaten whilst travelling together to create a measure of eating disruption. Playing at both a school and club increased this measure of disrupted eating in comparison to playing only for a club or only at school, suggesting that the number of training sessions that participants were attending had an impact on the security of their dietary intake.

6.5.4 Section 4: Sport specific nutrition

Water was the most popular drink participants chose between meals (78%) and was also the most popular drink taken around matches; 88% of participant drinking water in the hour before a match, 92% during a game and 88% after the game. Commercial bought and homemade sports drinks were also used before, during and after games, and commercial and homemade recovery drinks were used by 21% of participants. Water is recommended as the 'drink of choice' within the Eatwell Guide (Buttriss, 2016) and where food intake is adequate, should be recommended for sporting activity in young athletes (Bergeron, 2015). Adding flavouring to water has been found to increase voluntary drinking and improve hydration practices in adolescent male athletes (Wilk and Bar-Or, 1996) but this effect has not been found in adolescent females (Rivera-Brown*, et al.*, 2008; Wilk, Rivera-Brown, & Bar-Or, 2007), though the addition of electrolytes will improve retention of fluid (O'neal *et al.*, 2014; Rivera-Brown*, et al.*, 2008). Previous research has shown that youth athletes regularly arrive at training or matches hypo-hydrated, and the recommendation is to drink 5-7 $ml \cdot kg^{-1}$body weight of fluid 4 hours before exercise (Sawka*, et al.*, 2007; Thomas*, et al.*, 2016). Both hypohydration and

hyperhydration degrades athletic performance (Mcdermott *et al.*, 2017) and good hydration protocols are key for optimal performance. Studies have shown an increased prevalence of heat illness associated with sports and activity in younger athletes (Desbrow*, et al.*, 2019) and fluid deficits of >4% body weight have been found in adolescent athletes (14-17yr) competing in the heat (Aragón-Vargas, Wilk, Timmons, & Bar-Or, 2013).

Higher intake of sports drinks are found in adolescents who do higher levels of MVPA (Larson*, et al.*, 2014). Adolescent athletes, particularly pre-pubertal girls, have less fat free mass and lower glycogen stores than adults (Aucouturier, Baker, & Duche, 2008; Boisseau and Delamarche, 2000). Due to the reduced glycogen stores, exogenous sources of carbohydrate are of increased importance for maintained performance during high intensity exercise (Jeukendrup and Cronin, 2011). Exogenous carbohydrate is beneficial as it spares glycogen stores and this sparing effect may be greater in children (Montfort-Steiger and Williams, 2007). Although the use of carbohydrate containing sports drinks may offer benefits in children and adolescents, the standard sports drinks can lead to excessive carbohydrate consumption and weight gain (Field *et al.*, 2014) and are generally considered to be unnecessary (Desbrow*, et al.*, 2014). In the present study, participants recorded 8.9 ± 3.4 hours of activity a week, in 8.9 ± 4.0 sessions, suggesting that the average session was ~1 hr, meaning that water would be the recommended choice for the majority of sessions (Desbrow*, et al.*, 2019; Desbrow*, et al.*, 2014; Mcdermott*, et al.*, 2017). In the present study, 62% of participants reported that they did not eat during matches, 33% only drank water and 8% did not eat or drink. Having a better strategy for both hydration and carbohydrate intake may be beneficial in this group of female adolescent hockey players.

Sodas, fruit juices and energy drinks are not recommended during exercise as high sugar content and carbonation can slow the release of fluids from the stomach, causing

gastrointestinal distress and interfering with proper hydration (Rivera-Brown, 2016). Sugar sweetened beverages including sports drinks account for 30% of total free sugar intake in UK adolescents (11-18 yr) (Fairchild*, et al.*, 2017) and their intake should be monitored in young athletes.

The pre-match meal is of particular importance for the promotion of liver glycogen stores, particularly where the match is in the morning (Collins *et al.*, 2020; Nilsson, Fürst, & Hultman, 1973). In the present study, bananas were the most popular food eaten before matches, being chosen by 44% of participants. Bananas (and other fruit), pasta and wholegrain bread, would be considered good choices before a match, being relatively low glycaemic index, high carbohydrate sources. Traditionally high glycaemic foods were not recommended in the hour before activity due to the increased likelihood of developing reactive or rebound hypoglycaemia on the onset of exercise (Foster, Costill, & Fink, 1979) but the responses to foods eaten around sport are now understood to be highly variable and high glycaemic carbohydrates may be tolerated by some athletes (Volpe 2011). Likewise, in some individuals, high fibre or high fat foods eaten before or during activity can increase the risk of gastrointestinal distress (De Oliveira and Jeukendrup, 2013). High glycaemic index mono- or disaccharides (Jeukendrup, 2017) or high fat foods can also slow gastric emptying (Clegg and Shafat, 2009) and so energy delivery and should also be avoided. Unprocessed carbohydrate sources and low-fat options are generally recommended before and during sport (Thomas et al 2016). In the present study, 22% of participants did not eat in preparation for games, 22% choose high glycaemic index carbohydrates (carbohydrate gel, jelly sweets or white bread and jam) and 12% of participants chose high fat foods (nuts, crisps, cheese, chocolate biscuits).

The primary goal after training and competition should be to ensure suitable nutrition to support for recovery (Collins*, et al.*, 2020; Thomas*, et al.*, 2016). After the match, the majority of participants (83%) did eat or drink something but 11% only drank water. A

total of 39% of players reported that they usually have a match tea after games, 22% chose fruit and 9% pasta. Chocolate biscuits (15%) and crisps (13%) were also popular choices. Post-match meals and snacks should be good carbohydrate and protein sources (Burke, Van Loon, & Hawley, 2017) and rehydration of lost fluid is of key importance (Maughan, Leiper, & Shirreffs, 1996), fat should usually be avoided.

With regards to supplement use, 25% of participants recorded that they took a vitamin or mineral supplement with the most common taken being multivitamins, Vitamin C, Vitamin D, Calcium, and Iron. 3% of respondents said that they took a sports supplement. All 3% said that they took protein supplements, and one participant also took creatine. Supplement use amongst adolescent athletes is common (Desbrow*, et al.*, 2014) and are particularly popular with athletes looking for training adaptation or strength gains (Bloodworth, Petróczi, Bailey, Pearce, & Mcnamee, 2012). In a recent study of 348 international athletes (tier 4/5) (15-18 yr), Jovanov *et al.* (2019) found 82% of participants took a sports supplement, with 55% taking protein supplements. However, the number of female athletes taking the supplements was lower and supplement use increased with age (Jovanov*, et al.*, 2019). The participants in the present study were younger than those interviewed by Jovanov*, et al.* (2019) and were playing at a lower level which may explain these differences. A low use of supplements would be recommended as adolescent athletes should be able to get all the protein, minerals and vitamins they need from a well-balanced and varied diet (Desbrow*, et al.*, 2014).

Although the participants in the present study were matched for age and were all playing at a competitive level of hockey, there was a wider range of ages represented in the Main Study (9.0 – 17.2 yr), and a higher number of young players (38% <13 yr), than the Pilot Study (11.9 – 15.3, 13% <13 yr). This difference may have accounted to the difference in the number of hours and sessions played between the different studies and have caused an underestimation in the impact of playing competitive hockey during

adolescence. England Hockey rules prevent young hockey players from playing in adult leagues until they are 13 yr and the frequency of training and training loads often increase at this time.

Although the questions within the questionnaire came from independently validated questionnaires, these questionnaires had not been validated for use in adolescent hockey players and no tests had been done on item difficulty or the understandability of the complete questionnaire for the age group involved. Three different previously validated surveys were used but not all the questions from each questionnaire were included to reduce the questionnaire to a manageable size. Previous research has demonstrated a negative effect of questionnaire length on response rates and data quality (Revilla and Ochoa, 2017). These omissions reduced the overall length of the survey but made comparisons to previous research more difficult.

To conclude, adolescence is an important phase of physical and mental development during which good nutrition can be key to support performance and form good habits for life. Surveys provide a convenient and cost-effective method of data collection for use in the field to document self-report physical activity and dietary habits. However, these tools often give a distorted image of normal behaviour. In the present study, the participants as a group were moderately active, recording just over the national recommended amount of moderate to high intensity activity a week, however, there was quite a broad range of activity levels between individuals, with some doing more than the recommended amount of organised training a week. The majority of participants were eating three undisrupted meals a day. Breakfast was usually eaten at home and lunch was most commonly eaten as a cooked meal in a school dining room, but there was some evidence that as training levels increased there was an impact on eating behaviour, with more meals eaten whilst travelling, eaten at sports venues, or being skipped.

The present study has demonstrated the importance of the need to collectively understand physical activity and dietary behaviours in both daily-living and in sport and exercise specific settings. This information broadens the understanding of the challenges facing young athletes to meet the nutritional requirements for daily physical activity and sports specific requirements and can be used inform evidenced-based interventions to improve health and performance. As found in the physical activity and food diaries in Study 3, the PAQ-C questions showed that this group of adolescent hockey players were more active than the general population, having activity levels more similar to adolescent boys over the previous 7-days but it was not clear if this was consistent across the week or how it related to the rest of their school day and the sport they played. More detail on PA energy expenditure and how this varies over time is key if the best possible advice is to be given. Therefore Study 5 will investigate measuring energy expenditure using an accelerometer in addition to self-report food and activity diaries and GPS analysis. From the questionnaires used in Study 4, it was clear that eating behaviour around sport was not in keeping with current sports specific recommendations. It was not known if this was due to food accessibility and availability or because of poor nutrition knowledge. Questions on nutrition knowledge were added to the questionnaire used in Study 5.

7. STUDY FIVE: Physical Activity, Dietary Intake, Nutritional Knowledge and Eating Behaviour in Female Adolescent Hockey Players over a 7-Day period during the Hockey Season.

7.1 Abstract

The purpose of this study was to concurrently quantify physical activity, dietary intake, nutrition knowledge and eating behaviour in female adolescent hockey players during seven days within the competitive season. **Methods**: Female adolescent hockey players (n=36, 14.3 ± 1.3 yr; height 1.62. ± 7.4 m; body mass 53.5 ± 9.3 kg) wore the GeneActiv tri-axial accelerometer, completed a 4-day food and activity diary, wore a GPS for a training session and competitive match and completed a questionnaire on physical activity, eating behaviour and nutrition knowledge within a 7-day period. Independent T-tests and analysis of variance (ANOVA) tests with Bonferroni's post-hoc tests conducted to check significance. **Results**: EI (1,791 ± 313 kcal·d^{-1}) was lower than estimated EE from both the activity log (2,111 ± 322 kcal·d^{-1}) and GeneActiv (2,325 ± 354 kcal·d^{-1}). Dietary quality was poor as assessed by intake of saturated fat (14.0 ± 2.0% of energy), added sugar (31.7 ± 18.6g, 6.9 ± 3.4% of energy) and fibre (15.2 ± 4.0 g). The GPS data showed that, in comparison to matches, training had a higher proportion of low intensity activity (81 ± 7% vs 75 ± 8 % p<0.001) and lower moderate intensity activity (17 ± 7% vs 23 ± 8%, p<0.001). Distance (3,639 ± 969 m vs 4,283 ± 604 m, p<0.001), relative distance (38.4 ± 7.1 m·min^{-1} vs 77.7 ± 12.0 m·min^{-1}, p<0.001), maximum velocity (19.6 ± 2.2 m·s^{-1} vs 20.4 ± 2.0 m·s^{-1}, p=0.002) and EEE (5.9 ± 1.0 kcal·kg^{-1} vs 7.3 ± 1.0 kcal·kg^{-1}, p<0.001) were all lower during training than matches. **Conclusions**: Female adolescent hockey players have high EE, 38% played 3 or more sports competitively, which with regular hockey training and matches significantly added to the overall physical demands. Due to this higher demand and the time commitment involved participants may struggle to meet this energy demand through dietary intake.

7.2 Introduction

Quantifying EE and nutrient intake are crucial to inform evidence-based strategies to support adolescent athletes. Adequate dietary intake is important for sports performance and is vital to ensure optimal growth and development (Kerksick*, et al.*, 2017). Previous research in female athletes has identified hockey as a high-intensity game with higher recorded meter per minute distances than other comparable team sports (Mcmahon and Kennedy, 2019), high recorded heart rates for intensity of play (Mcguinness, Malone, Hughes*, et al.*, 2017) and increased energy demands due to the semi-crouched posture adopted by players (Elferink-Gemser*, et al.*, 2004). The GPS analysis of adolescent games in Study 2 confirms that this is also the case in female adolescent matches with match play characterised by intermittent sprinting, frequent changes of direction, hitting and dribbling the ball, jumping and diving collectively classifying hockey as a 'high intensity exercise' as identified in the adult game (Mcguinness, Malone, Petrakos*, et al.*, 2017). However, to understand the nutritional requirements of adolescent players it is important to not only understand the demands of their sport, but also to understand how these fit into the context of their other activity and the organised sports that they play. The energy requirements of adolescent athletes are highly variable (Carlsohn*, et al.*, 2011; Hannon, Parker*, et al.*, 2020; Petrie*, et al.*, 2004). Differences in the timing of growth, hours of activity and training loads, level of NEAT and the identified existence of compensatory sedentary behaviours, are all factors that make adolescent energy needs difficult to generalise (Burke, Melin*, et al.*, 2018; Desbrow*, et al.*, 2019; Petrie*, et al.*, 2004). Chronic low EI and poor EA can result in impaired growth and maturation, increased injury risk, delayed sexual maturation and health implications later in life (Loucks*, et al.*, 2011).

The adequacy of nutrient intake in UK adolescents has been shown to be sub-optimal. The National Diet and Nutrition Survey (NDNS, 2018) in the UK shows that female

adolescents in the UK aged 11 and 18 yr often have poor diets with low EI, low fruit and vegetable consumption and high consumption of saturated fat and added sugar. Low fruit and vegetable intakes are also regularly found in adolescent athletes and independently linked to poor bone health (New, 2003) and increased injury risk (Rosen*, et al.*, 2017). There have been no published literature investigating nutritional adequacy of female adolescent hockey players and information about the nutritional adequacy of female adult players is limited. Study 3 found that self-reported EI was lower than would be recommended and that although nutritional composition was within an acceptable range of current recommendations (Desbrow, 2021a) this was poorly distributed over the day and unlikely to be adequately fuelling the work required. The available studies within hockey have been on adult mixed-gender athletic populations and/or not specifically focused on hockey players (Nutter, 1991; Tilgner and Schiller, 1989; Van Erp-Baart*, et al.*, 1989; Wardenaar*, et al.*, 2017). LEA may be a particular concern for adolescent female athletes as they are more likely to be classified as 'highly specialised' than male athletes and playing on multiple sports teams (Post, Bell*, et al.*, 2017).

Disordered eating is common in competitive youth sport and the highest risk of eating disorders is during adolescence, coinciding with sports specialisation and increasing competition demands (Bergeron*, et al.*, 2015). Time constraints associated with training or competition can make achieving an adequate and balanced diet more difficult (Smith*, et al.*, 2015). Food choices can be dictated by food availability. Sport venues and school or college canteens frequently offer easy access to high energy, low nutrient snacks and beverages, such as chocolate bars, biscuits, crisps, protein bars, sports or energy drinks, and soft drinks (Naylor*, et al.*, 2015). Availability and accessibility of foods are powerful predictors of consumption during adolescence, with greater availability being related to greater intake (Cook*, et al.*, 2015). Higher consumption of fast or snack foods is also common with a greater proportion of meals eaten in the car or away from home (French*, et al.*, 2001; Thomas*, et al.*, 2012).

Meals eaten at home historically contain more protein and fat while snacks contain more carbohydrate and sugar (Summerbell*, et al.*, 1995). Both the total amount of carbohydrate and protein and the daily distribution of macronutrient intake is important within adolescent athlete's diets, modulating training adaptation, match performance and recovery (Philippou*, et al.*, 2017; Rossi *et al.*, 2017; Wasserfurth*, et al.*, 2020). The effect of the timing of carbohydrate intake on pre-exercise loading and performance is well documented (Burke*, et al.*, 2011; Jeukendrup, 2014) and there is now also evidence that the timing of protein intake may also be important, modulating muscle protein synthesis and recovery (Jennings*, et al.*, 2016; Philippou*, et al.*, 2017). There is currently no published research on the timing of macronutrient intake in adolescent hockey players.

Chronic low caloric intake and poor macronutrient balance may be unconscious, caused by lack of knowledge about appropriate nutrition and the need for optimal EB (Heaney*, et al.*, 2008). Eating a healthy diet is dependent on having both the knowledge of the nutrient value of food and the motivation to plan what to eat (Grunert, Wills, & Fernandez-Celemin, 2010). Most studies show that adolescent athletes have better nutrition knowledge than their non-athletic peers (Heaney*, et al.*, 2011) and that girls tend to have better nutritional knowledge than boys (Parmenter, Waller, & Wardle, 2000; Wardle, Parmenter, & Waller, 2000). However, adolescent athletes report relying on team coaches and the internet for nutrition knowledge (Abbey*, et al.*, 2017; Heaney*, et al.*, 2011) and as most studies have found coach knowledge is poor (Belski *et al.*, 2017; Cockburn, Fortune, Briggs, & Rumbold, 2014; Couture *et al.*, 2015) and the quality of dietary information on the internet is inconsistent (Hirasawa *et al.*, 2013; Trakman, Forsyth, Hoye, & Belski, 2019) it is possible for young athletes to pick up incorrect dietary information.

The present study's is designed to concurrently quantify EE, dietary intake, eating behaviour and nutritional knowledge in adolescent female hockey players to assess nutritional adequacy over a seven-day period during the hockey season. The more that is known about the athlete's 'usual' behaviour, the better the estimations of energy requirement and dietary intake can be, with fewer assumptions being made (Bentley*, et al.*, 2020). The aim of the present study is to (1) calculate EB and EA using a measured EE and EEE to assess whether energy intake is adequate, (2) analyse diet quality and nutritional knowledge in this group.

7.3 Methods

7.3.1 Study Design

Thirty-six female participants (14.3 ± 1.3 yr; height 1.62. ± 7.4 m; body mass 53.5 ± 9.3 kg) volunteered to participate for a combined physical activity and nutrition study during the 2019/20 hockey season. All the participants were playing for a West Sussex school's age group A or School 1st team and were either registered in England Hockey's Single system or judged to be playing at an equivalent level by their school coach. Ethical approval for the study was obtained from the University of Chichester Research Ethics Committee. All participants were given a written and verbal briefing on the purpose of the study and provided written informed consent. The study ran for seven days in November 2019 and was conducted in four parts: 1) Collection of anthropometric measurements and assessment of developmental age 2) measurement of physical activity using a survey and tri-axial accelerometer, 3) GPS analysis of both training and match play and 4) dietary analysis using a 4-day food and activity diary and a questionnaire on food choices, nutrition knowledge and usual eating behaviour.

7.3.2 Anthropometric Measurement

Standing and seated height was measured to the nearest 0.01 m in accordance with ISAK guidance using a Harpenden G133 Portable stadiometer (Holtain ltd, Dyfed, UK) and body mass was measured to the nearest 0.1 kg (Mettler Toledo PB3001-s Scales, Fisher Scientific UK). These measures were used to calculate a gauge of developmental age or maturity offset from chronological age using equations developed by Mirwald*, et al.* (2002) using the method described in section 3.3. Predicted adult height was used to estimate remaining growth in cm (Sherar*, et al.*, 2005).

Participants Body Mass Index (BMI) was calculated and used to estimate participants percentage body fat percentage from the equations developed by Jackson *et al* (2002) using the method descried in section 3.3 and an estimation of EA was calculated.

7.3.3 Physical Activity Monitor

Participants were asked to wear a wrist-mounted tri-axial accelerometer to measure physical activity (GENEActiv Original, Activinsights Ltd., Cambridge, UK) for 7-days in which they were involved in a normal school term time timetable. The GeneActiv monitors were fitted dorsally on the participants non-dominant wrist on day 1 of the study week. Participants were told that the GENEActiv monitors were waterproof and that they should be worn constantly day and night. The GENEActiv measures tri-axial seismic acceleration ranging in magnitude ± 8g sensitivity and was set at a sample frequency of 50 Hz. Accelerometers were configured to each user setting age, body mass, height, and the wrist on which it was worn using GeneActiv software version 3.1 (Activinsights, Cambridge, UK). Data was analysed using a Microsoft Excel® (Microsoft Corporation, Redmond, WA, USA) macro analysis spreadsheet supplied by Activinsights. Raw acceleration data collected at 50 Hz was converted on analysis into 60 second epochs. The gravity-subtracted sum of vector magnitudes (SVMs) for each minute were used to

estimate metabolic equivalents (METs) using previously validated thresholds in adolescents (Phillips*, et al.*, 2013). Basal Metabolic Rate (BMR) was estimated using Oxford Equations (Henry, 2005) and used to calculate daily and hourly EE. PAL was calculated using the equation PAL = TEE / BMR. Sleep time was taken as being the hours between 11pm and 5am, divided into two three-hour sections, with the time of sleep and waking taken estimated from the GeneActiv raw data. Waking hours were divided into three-hour epochs; 0500 – 0800, 0801 – 1100, 1101 – 1400, 1401– 1700, 1701 – 2000 and 2001 – 2300. Days with >65% wear time were considered valid and only participants with at least 6 valid days were included within the analysis.

7.3.4 Physical Activity Questionnaire

On day 7 of the study, the participants completed a paper questionnaire to recall their physical activity during the previous 7-days. These questions were part of the larger 40-question survey (Appendix B, Main Survey, Q4-19). The physical activity questions within the questionnaire were aligned with questions from an adapted PAQ-C for the UK (Voss*, et al.*, 2013; Welk and Eklund, 2005). The PAQ-C was scored as detailed by Kowalski et al. (2004) but using the version updated for English youth by Voss et al. (2013) and Aggio*, et al.* (2016) and the cut-off bands recommended by (Kolimechkov*, et al.*, 2017). Medium physical activity was assumed to have a PAQ-C summary value of >2.5 and <3.5 (Kolimechkov*, et al.*, 2017).

7.3.5 GPS and Heart Rate

To quantify the match and training activity levels, a training session and a match held in school time were analysed using the methods outlined in section 4.3.2. The pitch coordinates were logged within the Catapult Software and the velocity bands were set amalgamating those used in U16 hockey players by Leslie (2012) for the moderate and high intensity bands, with cut-offs used for low intensity bands by Macutkiewicz and

Sunderland (2011) as shown in Table 7.1. Time on the substitute bench was not analysed or included in any calculations of rest or low intensity exercise, but time spent listening to instruction within training was included.

Table 7.1 GPS Speed Zones ($m \cdot s^{-1}$) adapted from bands given within Macutkiewicz and Sunderland (2011) for the lower intensities and those adjusted by Leslie (2012) for moderate and high intensity bands.

Speed ($m \cdot s^{-1}$)	Description	Speed Bands
0-0.17	Standing	LOW
0.19-1.67	Walking	
1.69-2.77	Jogging	MODERATE
2.80-4.02	Running	
4.05-5.28	Fast running	HIGH
>5.31	Sprinting	

Total distance, time on the pitch, movement velocity, heart rate and power data were downloaded into excel for analysis. EE during the training session and match were estimated by using the accelerometer data from the GPS device (Catapult OptimEye s5) to derive an EE from metabolic power using the model proposed by Di Prampero*, et al.* (2005), EEE was used to calculated a measure of EA.

7.3.6 Nutrition Habits and Intake

To estimate mean daily intake of energy, nutrients, and food items, a 4-day food and activity record was requested using the methods outlined section 5.3.2 and 5.3.3. Additional detail on usual food choices and eating behaviour was given by each participant as part of the written questionnaire (Appendix B. Main Study, Q31-35). All

activity and organised exercise sessions were also recorded on the diary. The food and activity diary and questions on food choices and eating behaviour were adapted from the ROOT Study (Goodyer*, et al.*, 2010), with questions in section 5 of the questionnaire being specifically designed to clarify food choices included within the 4-day record if these were not clear. Diaries were analysed for energy and macronutrient content and split by the time that the food items were eaten. In this secondary analysis, meals were split into 6 time periods to match the breakdown of the GeneActiv physical activity data: 0500 – 0800, 0801 – 1100, 1101 – 1400, 1401– 1700, 1701 – 2000 and 2001 – 2300. Only diaries that contained three complete days, with two consecutive weekdays, and one day at the weekend, and where the timing of meals was given were included within the analysis. 3-day food diaries including week-days and weekend days, with parental checking has been found to be an accurate way of recording intake in children and adolescents (Burrows, Martin, & Collins, 2010). To identify record of poor validity, participants were classified as under-reporters, average reporters or over-reporters from their individual ratio of reported EI to TEE according to Black (2000). Average reporters were identified by an EI/TEE ratio of 0.76-1.24, under-reporters by a ratio <0.76 and over-reporters >1.24.

In order to understand whether sports participation had an influence on eating behaviour, the location and frequency of eating breakfast, the number of times lunch and dinner were skipped and the number of evening meals eaten whilst travelling were ranked and used to create a novel measure of eating disruption, using the method outlined section 6.3.4.

The questionnaire also included 10 questions designed to test nutrition knowledge taken from the General Nutrition Knowledge Questionnaire (GNKQ) originally designed by Parmenter and Wardle (1999) but utilising the updated answers by Kliemann *et al.* (2016). The GNKQ was scored according to the original design by Parmenter and Wardle

(1999) using a negative mark scheme. These questions can be found in the main study questionnaire in Appendix B, Q36-45.

7.3.7 Statistics

Data was analysed using JASP Team (2020) version 0.13.1. Dependent variables were calculated for all data sets and summarised as the mean and standard deviation. Data was checked for skewness and kurtosis and found to be normally distributed. A Pearson Correlation was used to examine the strength of the linear relationship between variables of age, developmental age, BF%, hours of activity, PAQ-C score, GNKQ score, a novel measure of disrupted eating, pack lunch and take-away consumption and the intake of saturated fat, sugar and fibre, and also between estimated and measured energy expenditure, kilocalories expended during matches and training, distance and relative distance covered and average daily energy intake over a four day period. In accordance with Cohen 1988 a correlation of >0.5 was classified as large, 0.5-0.3 as moderate. 0.3-0.1 small and anything smaller than 0.1 as insubstantial (Cohen, 1988). Time on the pitch, match distance, relative distance, speed, and the percentage of time spent in three speed zones were compared for the three on-field pitch positions (forward, midfield and defence) using Analysis of Variance (ANOVA). Paired T-tests were used to compare the difference between sugar, CHO, EI and energy deficit, and performance measures during training and match play. Statistical significance was accepted at $p<0.05$

7.4 Results

Of the 36 participants who volunteered for the study, seven were removed from the final analysis, therefore, all data are reported for 29 participants. One participant was removed

from the final results as the GENEActiv she was wearing malfunctioned. Four participants were removed as wear time was below 65% on two or more days. A further two participants were removed as they had incomplete food and activity diaries. Using the Estimated TEE, only 4 diaries (13.8%) were calculated to have poor validity, all due to underreporting intake (Black, 2000).

7.4.1 Anthropometry

Table 7.2 presents the anthropometric and physiological characteristics of the participants.

Table 7.2 Anthropometric and physiological characteristics of female adolescent hockey players and the number of hours and sessions of sports played over the previous 7 days. Data is expressed as mean ± standard deviations and the range of values measured across all participants.

N=29	Mean ± SD	Range
Height (cm)	161.3 ± 7.1	152.8 – 179.2
Body Mass (kg)	53.2 ± 9.4	34.9 – 81.8
Estimated BF%	21.6 ± 3.9	15.7 – 35.2
Chronological age (yr)	14.4 ± 1.3	12.4 – 16.6
APHV (yr)	12.6 ± 0.5	11.8 – 13.6
Remaining Growth (cm)	3.9 ± 3.5	0.0 – 13.7
Predicted Adult Height (cm)	165.2 ± 5.3	157.5 – 179.4
Hours of organised sport (7-days)	9.4 ± 2.5	6 - 16
Organised sport sessions (7-days)	9.1 ± 2.6	3 - 14

A total of 48% of participants were assessed as average maturing (APHV between 10.9 and 12.9) and 52% as late maturing (APHV > 12.9). There were no participants assessed as being early developers as defined by Kozieł and Malina (2018). Chronological age, APHV and remaining growth were not related to BMI, calculated BF% or associated with any measure of physical activity. There was no association between APHV and estimated EE, but GeneActiv measured EE was negatively correlated with the TPHV (r=0.44, p=0.02) and positively correlated to remaining growth in cm (r=0.42, p=0.02) suggesting lower deficits were reported where growth was likely to be highest. Table 7.2 also shows self-reported hours of organised sport played, and number of sessions attended over the previous 7 days.

7.4.2 Physical Activity

Table 7.3 PAQ-C score and results of the individual PAQ-C questions for female adolescent hockey players in the present study compared to the values given for female adolescents by Voss *et al* 2017 and Kolimechkov *et al* 2017. PAQ-C values were scored by assigning a value of between one and five in order of activity intensity in line with scoring by Kowanski *et al* 2004. Data is expressed as mean ± standard deviations and the range of values measured across all participants.

	Present study	Values from Voss *et al* 2013 (English school girls 10 – 16 yr)	Values from Kolimechkov *et al* 2017 (English school girls 7-10 yr)
PAQ-C Hours played	3.1 ± 0.9	2.7 ± 0.6	2.6 ± 0.8

PAC-Q Score for before school	3.0 ± 0.8	N/A	N/A
PAQ-C Score for morning break	2.7 ± 1.4	3.5 ± 1.2	4.3 ± 1.0
PAQ-C Score for Lunch break	3.7 ± 1.6	2.41 ± 1.0	4.3 ± 1.0
PAQ-C Score for After School	4.0 ± 0.9	2.7 ± 1.2	2.8 ± 1.4
PAQ-C Score for Weekend activity	3.6 ± 1.1	2.7 ± 1.0	3.1 ± 1.4
PAQ-C Score Week summary	3.3 ± 0.5	2.7 ± 0.6	3.17 ± 0.7

Table 7.3 shows the self-report physical activity values for each individual PAQ-C question, the weekly PAQ-C score, and comparison with research by Voss *et al* (2013) and Kolimechkev *et al* (2017). PAQ-C score was negatively correlated to age (r=0.49, p=0.07) in both studies. Participants in the current study (14.3 ± 1.3 yr) were ranked as being more active during each time frame; before school, morning break, lunch break, after school and at weekends (p<0.001) than participants in Study 4 (13.6 ± 2.0 yr) in this thesis and, than in either published study considering the comparative ages. 38% of participants played two or more other sports competitively as well as hockey, 14% did regular swim training before school.

Table 7.4 shows the percentage wear time, the average EE, EE per kilogram of body weight and a calculated physical activity level (PAL) for each day as measured by the GeneActiv wrist bands.

Figure 7.1. shows measured EE (GeneActiv) divided into 8, 3-hour time epochs over the 7-days. Low EE was seen during the time between 2301 and 0500 which was classified as night. The higher measured EE were seen within the time periods where participants

had recorded having training and matches. Timetabled hockey sessions were on Monday afternoon (training), Tuesday afternoon (U13 & 1st Team match) and Friday lunchtime (U14 Cup Match). In the food and activity diaries, 64% participants reported either having trained or played a match on Sunday.

Table 7.4 Measured energy expenditure, Physical Activity Level, kcal·kg^{-1} and average wear time for each day taken from GeneActiv wrist bands worn by female adolescent hockey players over a 7-day period. Data is expressed as mean ± standard deviations and the range of values measured across all participants.

	Energy Expenditure (kcal) Mean ± SD	kcal Range	PAL Mean ± SD	PAL Range	kcal·kg^{-1}	% time worn
Monday	2324 ± 501	1187 – 3500	1.7 ± 0.3	1.1 - 2.1	43.7 ± 6.0	98.5 ± 6.0
Tuesday	2438 ± 462	1705 – 3640	1.8 ± 0.3	1.3 - 2.4	46.2 ± 6.9	97.5 ± 6.0
Wednesday	2262 ± 462	1641 – 3094	1.6 ± 0.2	1.3 - 2.4	42.8 ± 4.9	98.3 ± 3.0
Thursday	2348 ± 395	1748 – 3251	1.6 ± 0.3	1.2 - 2.1	44.5 ± 5.9	96.0 ± 8.0
Friday	2020 ± 460	1172 – 3227	1.5 ± 0.2	1.0 - 2.0	38.0 ± 5.6	98.1 ± 4.0
Saturday	2347 ± 319	1837 – 3226	1.7 ± 0.2	1.3 - 2.1	44.7 ± 5.6	97.3 ± 6.0
Sunday	2479 ± 496	1614 – 3309	1.8 ± 0.3	1.3 - 2.4	46.8 ± 6.6	99.0 ± 3.0
Average of days	2317 ± 65	1577 – 3312	1.7 ± 0.2	1.2 - 2.2	43.8 ± 3.1	97.8 ± 2.65

Figure 7.1 Total energy expenditure on each of the 7-days divided by the time epoch as measured by wrist worn GENEActiv in female adolescent hockey players. Data is expressed as mean for all participants.

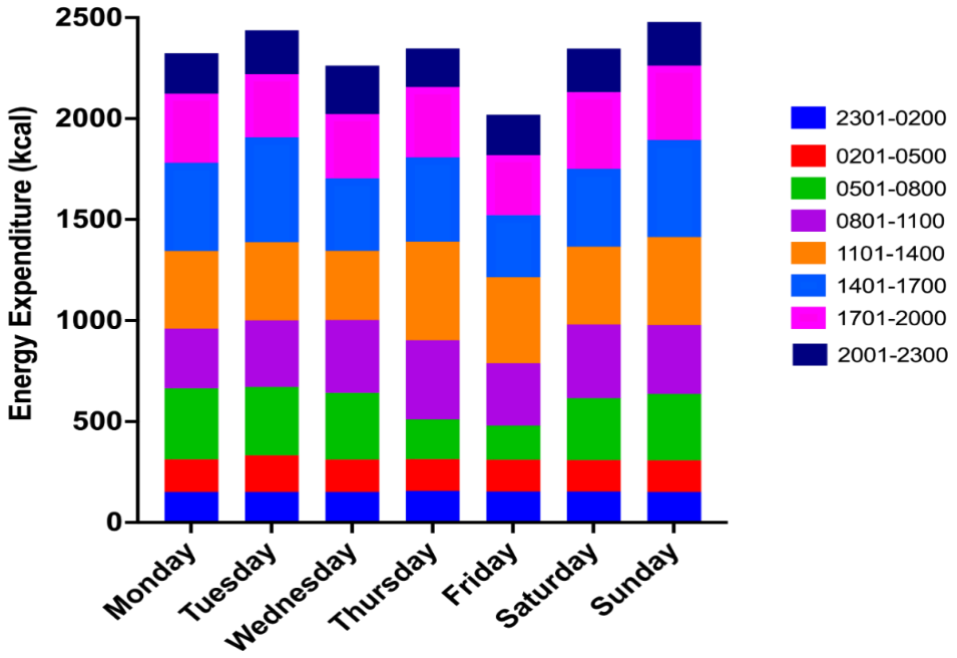


Figure 7.2 Total energy expenditure on each of the 7-days split into hours as measured by wrist worn GENEActiv in female adolescent hockey players. Data is expressed as the mean of all participants.

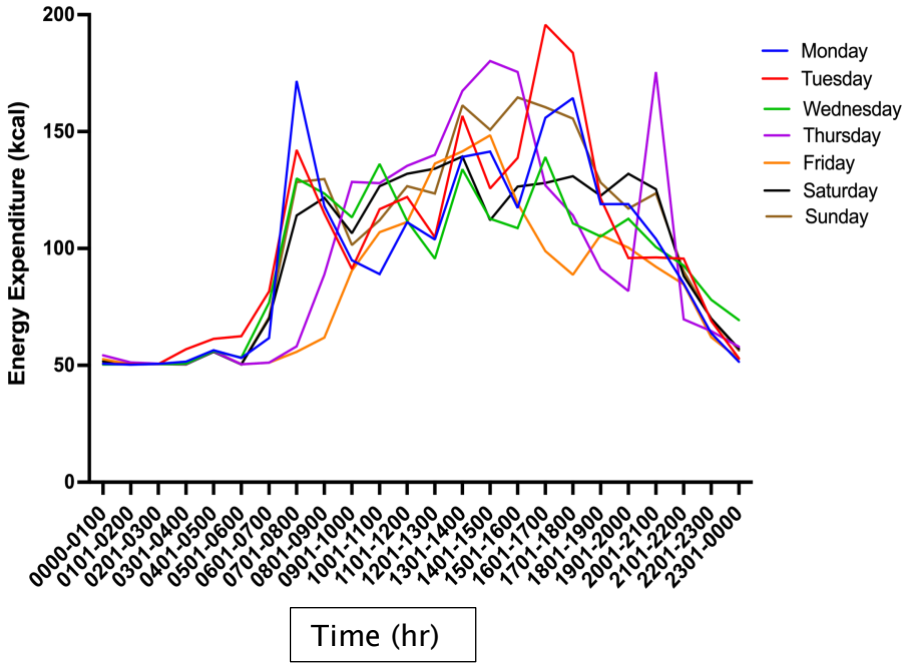


Figure 7.2 shows measured EE over each hour on the 7-days as measured by the wrist worn GeneActiv. Participants recorded activity done within their food diaries. Nine participants swam before school on the recorded days, and the PAQ-C score for before school activity (3.0 ± 0.8) was high. In the present study all participants played in a school team and 29% also played for a club, club hockey training was on Tuesday and Thursday evening. 52% of participants had been selected within the single system and 24% played in either performance centre or national age group teams.

7.4.3 Training Sessions and Match Analysis

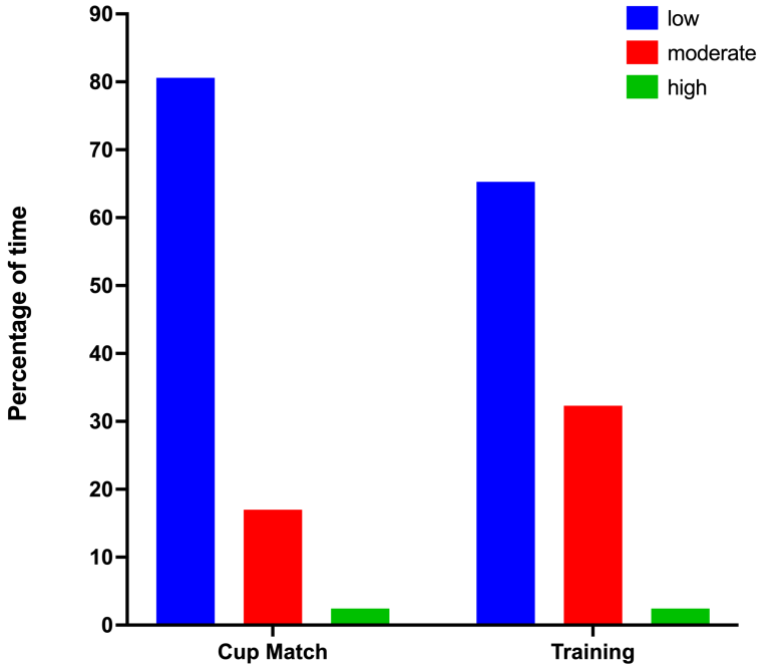
Table 7.5 shows EE during the monitored training session and match calculated from metabolic power and the analysis of movement intensity from the Catapult GPS. Distance covered ($p < 0.001$), relative distance ($p < 0.001$), maximum velocity ($p = 0.002$) and EE per kg body weight ($p < 0.001$) were all lower during training than in the matches played.

Figure 7.3 shows the differences in the movement in the different velocity bands in training and match play. Individual players time spent in low velocity bands during training was higher ($p=0.02$) than the same players match-play, and the amount of moderate intensity activity was lower ($p=0.01$). EI was associated with measured EEE ($kcal \cdot h^{-1}$, Catapult GPS) during training ($r=0.4$, $p=0.03$) but not EEE during the match. Distance covered during training or the match in $m \cdot min^{-1}$ was not linked to any measure of EB or EA but was positively associated to the calculated measure of disrupted eating ($r=0.4$, $p=0.03$) over the 7-days. Average EE was 2,327 ± 65 $kcal \cdot d^{-1}$, EEE during a measured training session was 315 ± 90 kcal and a match 386 ± 85 kcal. On an individual basis training accounted for 14% (7 – 21%) and a match for 17% (12 – 22%) of daily measured EE.

Table 7.5 Time on the pitch, distance, velocity, energy expenditure and percentage time in each velocity band (low, medium, high) measured by GPS in female adolescent hockey players. Velocity bands were set as low intensity 0-1.67 m·s^{-1} (stand and walk), moderate intensity 1.69-4.02 m·s^{-1} (jog and run) and high intensity as >4.05 (fast run and sprint). Data expressed as mean ± standard deviation (SD) for a training session and a cup match played during a 7-day period. Differences between the training session and match are expressed by * p < 0.05, ** p < 0.01, *** p < 0.001.

GPS Values		
	Training	Match
Time on pitch (mins)	95.0*** ± 18.3	55.7*** ± 7.2
Total distance (m·session^{-1})	3,639*** ± 969	4,283** ± 604
Relative distance (m·min^{-1})	38.4*** ± 8.3	77.7*** ± 12.0
Max velocity (km·h^{-1})	19.6** ± 2.2	20.4 ± 2.0
EE (kcal·kg^{-1})	5.9***,** ± 1.0	7.3** ± 1.0
EE (kcal·session^{-1})	315*** ± 9	386*** ± 85
EE (kcal·h^{-1})	201 ± 51	423 ± 110
Low intensity – stand & walk (%·session^{-1})	81* ± 7	75* ± 8
Medium intensity – jog & run (%·session^{-1})	17** ± 7	23**,* ± 8
High intensity – fast run & sprint (%·session^{-1})	2 ± 1	2 ± 1

Figure 7.3 GPS percentage time spent in the velocity bands assigned for high, moderate, and low intensity activity demonstrating the difference between training and match play. Velocity bands were set as low intensity 0-1.67 m·s^{-1} (stand and walk), moderate intensity 1.69-4.02 m·s^{-1} (jog and run) and high intensity as >4.05 (fast run and sprint).



7.4.4 Nutrition

7.4.4.1 Energy Balance and Energy Availability

Figure 7.4 shows individual participants EB for both the measured (GeneActiv) and estimated EE for each participant. EB = EI – EE.

Figure 7.4 Individual Energy Balance (EI – EE)) using both estimated and measured energy expenditure for each of the 29 female adolescent hockey players.

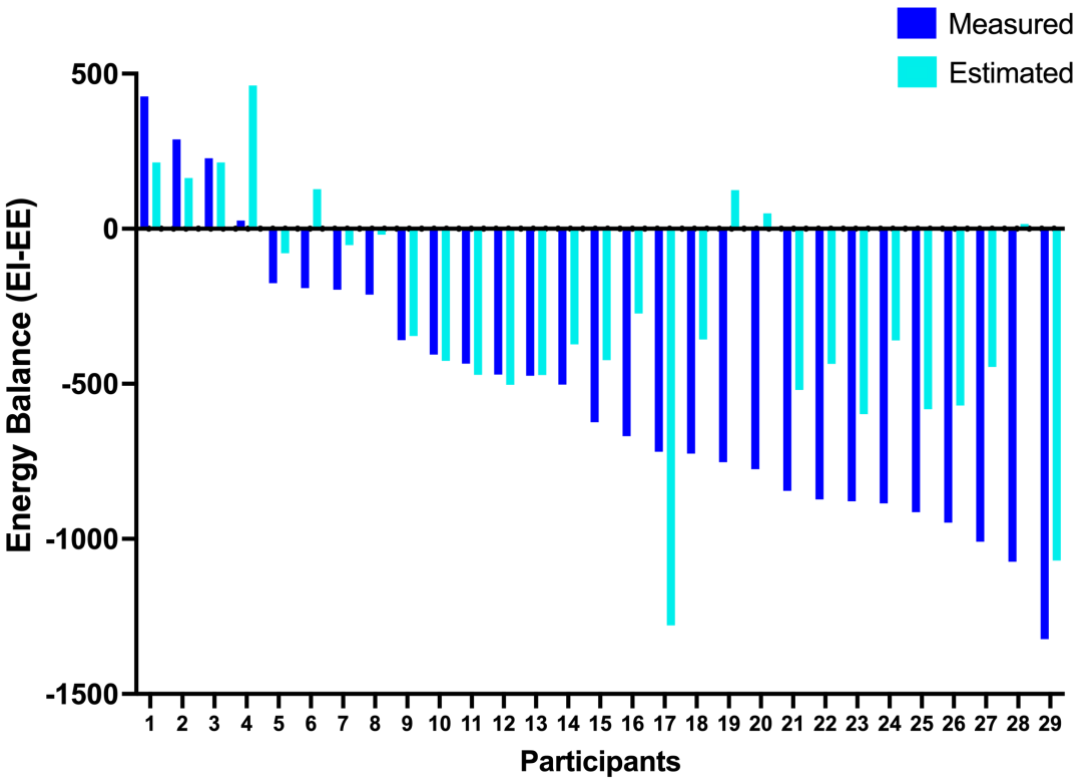
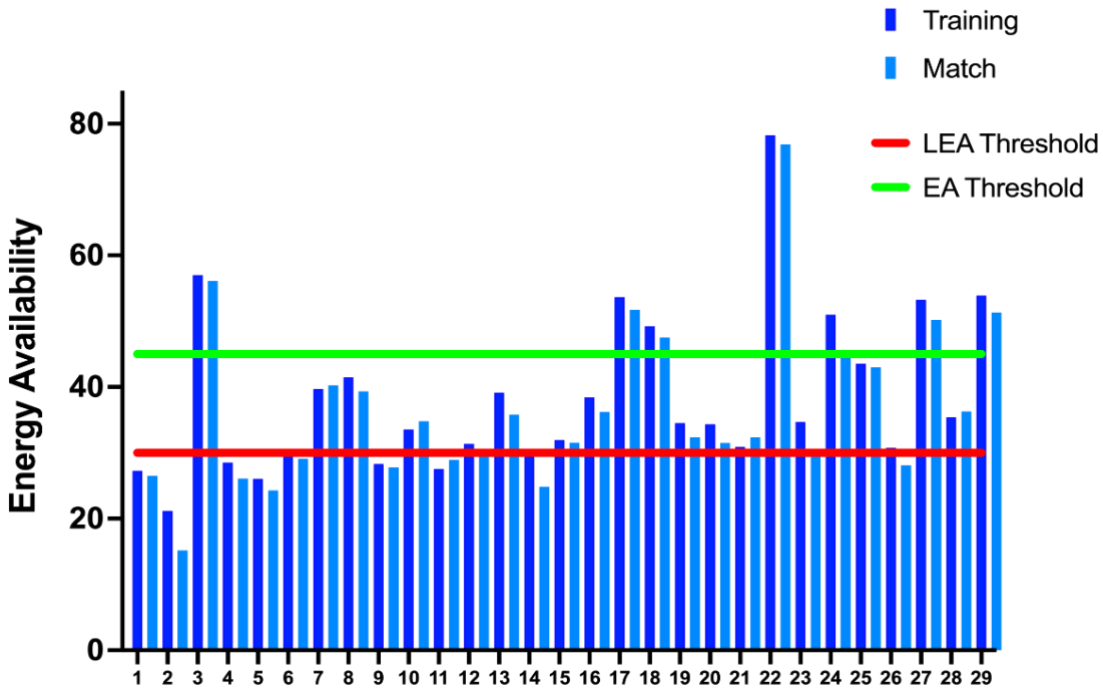


Figure 7.5 shows EA on match and training days. EA being calculated using the EEE calculated from metabolic power measured by GPS. EA = (EI – EEE) / kg FFM.

Figure 7.5 Individual Energy Availability calculated using exercise energy expenditure during a training session and a match for each of the 29 female adolescent hockey players, compared with the thresholds for low energy availability (LEA) below which severe health consequences exist (<30 kcal·kg·FFM^{-1}·d^{-1}) and the energy availability (EA) expected for energy balance (45 kcal·kg·FFM^{-1}·d^{-1}). Energy availability = (EI – EEE) / Kg FFM



7.4.4.2 Dietary Intake

Table 7.6 shows the analysis of the food element of the four-day food and activity diaries. The estimated EE for the participants was based on PAL values of 1.4-1.5 selected on the bases of the activity recorded. These estimates were lower than the PAL values calculated from the measured activity (1.7 ± 0.2, range 1.2 - 2.2). EA was calculated for match days and training days using the EEE measured for a training session and match using the Catapult GPS.

Reported EI increased with hours of activity done (r=0.4, p=0.03) but was not related to any other self-report measure of physical activity or PAQ-C score. Free sugar intake was higher than recommended at 7 ± 3% of total EI and was positively associated with an increasing energy deficit between the reported intake and both estimated (r=0.5, p=0.006) and measured (r=0.6, p=0.001) EE, and the calculated measure of disrupted eating (r=0.4, p=0.04). Sugar intake but not the intake of any other food or nutrient increased with self-report hours of activity (r=0.4, p=0.02). FV intake was associated with high fibre intake (r=0.7, p<0.001).

7.4.4.3 Distribution of Dietary Intake

Figure 7.6 shows the daily distribution of EI and EE across the 6-time epochs and Figure 7.7 shows the daily distribution of macronutrient intake. Across all participants in the present study. Intake of energy and all macronutrients was higher at times that would represent the three main meals, (breakfast, lunch, and dinner), with smaller snacks in the time periods between. Intake of protein and fat were higher in the evening meal, but carbohydrate amounts were distributed evenly across all timeframes. Percentage of EI from carbohydrates was 49 ± 6%, from protein was 16 ± 2% and from fat was 36 ± 5%. Carbohydrate and protein intake were very close to the government recommendations for the general population, (50-55% carbohydrate and 10-15% protein) but the intake of carbohydrate was lower than recommended in active individuals (4.4 ± 1.7 $g \cdot kg^{-1} \cdot d^{-1}$ vs 5-6 $g \cdot kg^{-1} \cdot d^{-1}$ advice). Intake of total fat (35.6 ± 5.4 % vs 30-35% advice) and particularly saturated fat (14.0 ± 2.0 % vs 11% advice) was high.

Table 7.6 Nutrient Intakes measured over a four-day period in female adolescent hockey players. Recommended intakes based on COMA (1991) values or those recommended for adolescent athletes (Desbrow*, et al.*, 2014). Measured and estimated energy expenditure was used to calculated energy balance and a measure of energy availability. Data expressed as mean ± standard deviation.

Nutrient	Intake	RNI
Estimated EE (kcal·d^{-1})	2111 ± 322	2223 - 2342
Measured EE (GeneActiv)	2325 ±354	2223 - 2342
EI (kcal·d^{-1})	1791 ±313	N/A
Estimated EB (kcal·d^{-1})	--320 ±503	N/A
Measured EB (kcal·d^{-1})	-534 ±428	N/A
EA Match Days kcal·kg·FFM^{-1}·d^{-1}	36.6 ±12.4	>45 kcal·kg·FFM^{-1}·d^{-1}
EA Training Days kcal·kg·FFM^{-1}·d^{-1}	38.4 ±12.4	>45 kcal·kg·FFM^{-1}·d^{-1}
Fruit and Vegetables·day^{-1}	3.1 ±1.4	5+ a day
Carbohydrate (%)	49.2 ±6.0	50-60%,
Carbohydrate (g·kg^{-1}·d^{-1})	4.4 ±1.7	5-6 g·kg^{-1}·d^{-1}
Protein (%)	16.1 ±2.4	10-15%,
Protein (g·kg^{-1}·d^{-1})	1.4 ±1.7	1.3-1.8 g·kg^{-1}·d^{-1}
Fat (%)	35.6 ±5.4	20-25% < 35%
Fat (g·kg^{-1}·d^{-1})	1.4 ±0.4	N/A
Added Sugar (g)	31.7 ±18.6	Adults/children >11 yr <30 g·d^{-1}
Added Sugar (%)	7 ±3	5% EI
Saturated Fat (g)	27.7 ±7.0	Women <20 g, Children <11 g
Saturated Fat (%)	14.0 ±2.0	11% EI
Fibre (NSP) (g)	15.2 ±4.0	11-16 yr 25 g·d^{-1} 17yr+ 30 g·d^{-1}

Figure 7.6 Daily Distribution of Energy Intake and Energy Expenditure in adolescent hockey players across six-time epochs. Energy intake data expressed as mean ± standard deviation. Energy expenditure is expressed as a mean value.

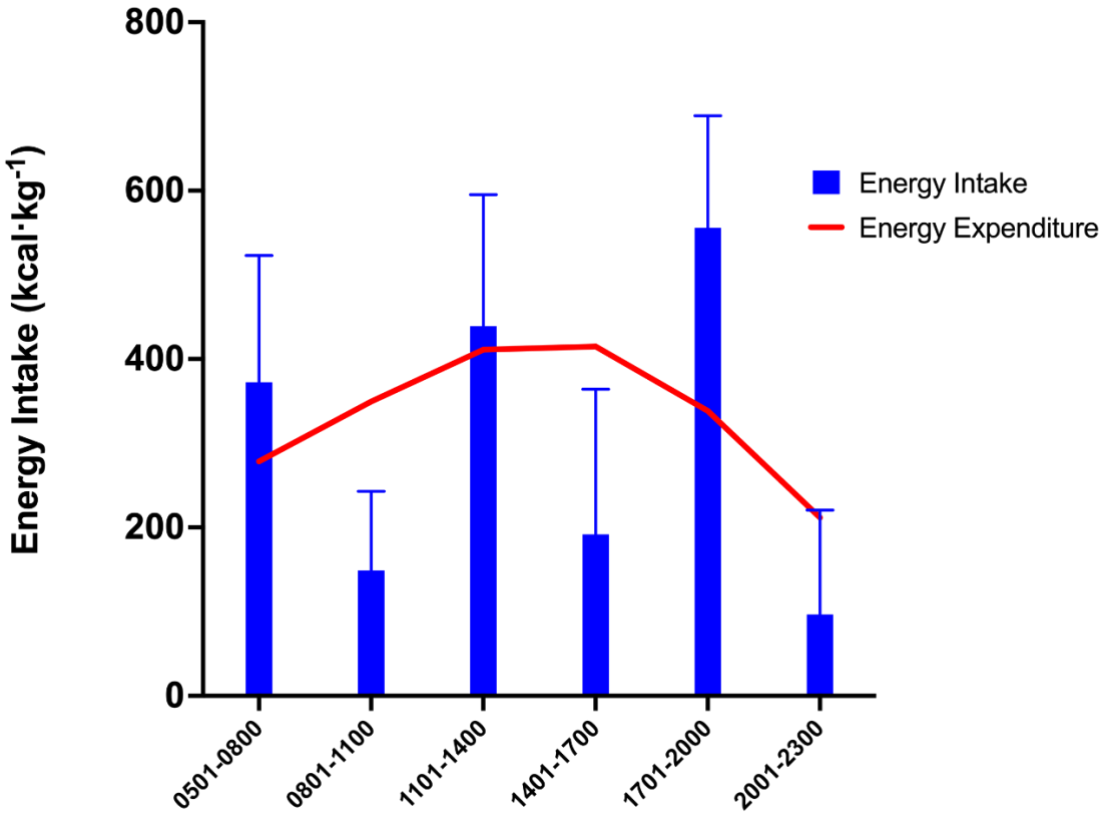
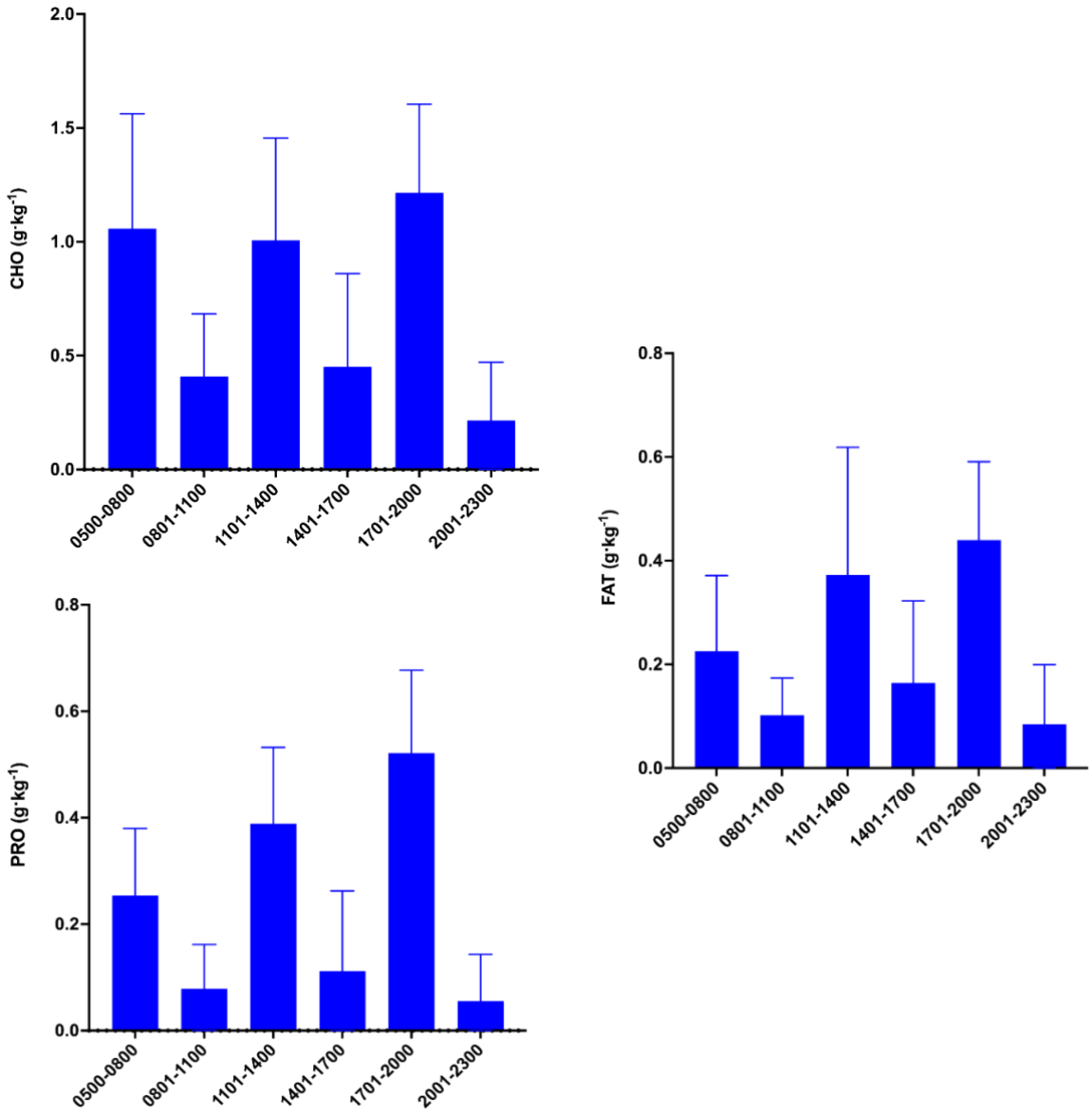


Figure 7.7 Daily Distribution of macronutrients; Carbohydrate, Protein and Fat in grams intake, in adolescent hockey players across six-time epochs. Data expressed as mean ± standard deviation.



7.4.4.4 Eating Behaviour

As part of the final questionnaire, participants were asked about their eating behaviour, and where they ate their meals during the seven days of the study. The survey showed good consistency of intake with 97% of participants reporting that they ate breakfast at

least 5 times in the last 7-days with 56% always eating breakfast at home. A cooked lunch was the most common with 79% of participants recorded that they ate a cooked lunch in the school dinning room at least four times in the last week.

A total of 38% of participants had a packed lunch either prepared at home or by the school at least once in the last week and 17% of participants skipped lunch at least once a week. In the evening, 93% of participants recorded that they ate a meal that was prepared, cooked and eaten at home at least four times over the week but all of the participants ate in a restaurant or sports club, had a take away or a ready meal at least once in the previous week. Two participants reported skipping an evening meal. The ranked indicators of disrupted eating gave a mean score of 4.6 ± 0.5.

7.4.4.5 Nutrition Knowledge

Figure 7.8 shows the average scores for each set of questions within the nutrition knowledge questionnaire. Using the negative mark scheme as designed by Parmenter and Wardle (1999) over the 10 questions (40 answers), the participants scored 11.0 ± 8.0 out of a possible mark of 40 (27.5%). The highest scoring questions were on fruit and vegetable recommendations where 86% of participants gave the correct answer and protein, with 69% being correct. The weakest questions were on food processing (24%) and current nutrition advice (34%).

Figure 7.8 Nutrition knowledge scores for participants in Study 5. F&V= How many servings of fruit and vegetables do experts advise people eat? SUGAR= Do you think these foods and drinks are typically high or low in added sugar (average of 7 foods)? SALT= Do you think that these foods and drinks are typically high or low in salt (average of 6 foods)? FIBRE= Do you think these foods and drinks are typically high or low in fibre (average of 6 foods)? PROTEIN= Do you think these foods are a good source of protein (average of 6 foods)? FAT= Do you think these foods are high or low in fat (average of 7 foods)? NUTRIENTS & PROCESSING= Average of four questions (1) The amount of calcium in a glass of whole milk compared to a glass of skimmed milk is? (2) Which of the following nutrients has the most energy (calories) for the same weight of food? (3) Compared to foods that have not been processed, processed food is usually, higher in calories, higher in fibre, lower in salt or not sure? ADVICE= Do health professionals or nutritionists recommend that you eat more, the same amount or less of the following foods. Fruit, foods with added sugar, fatty foods, processed meat, wholegrains, salty food, water.

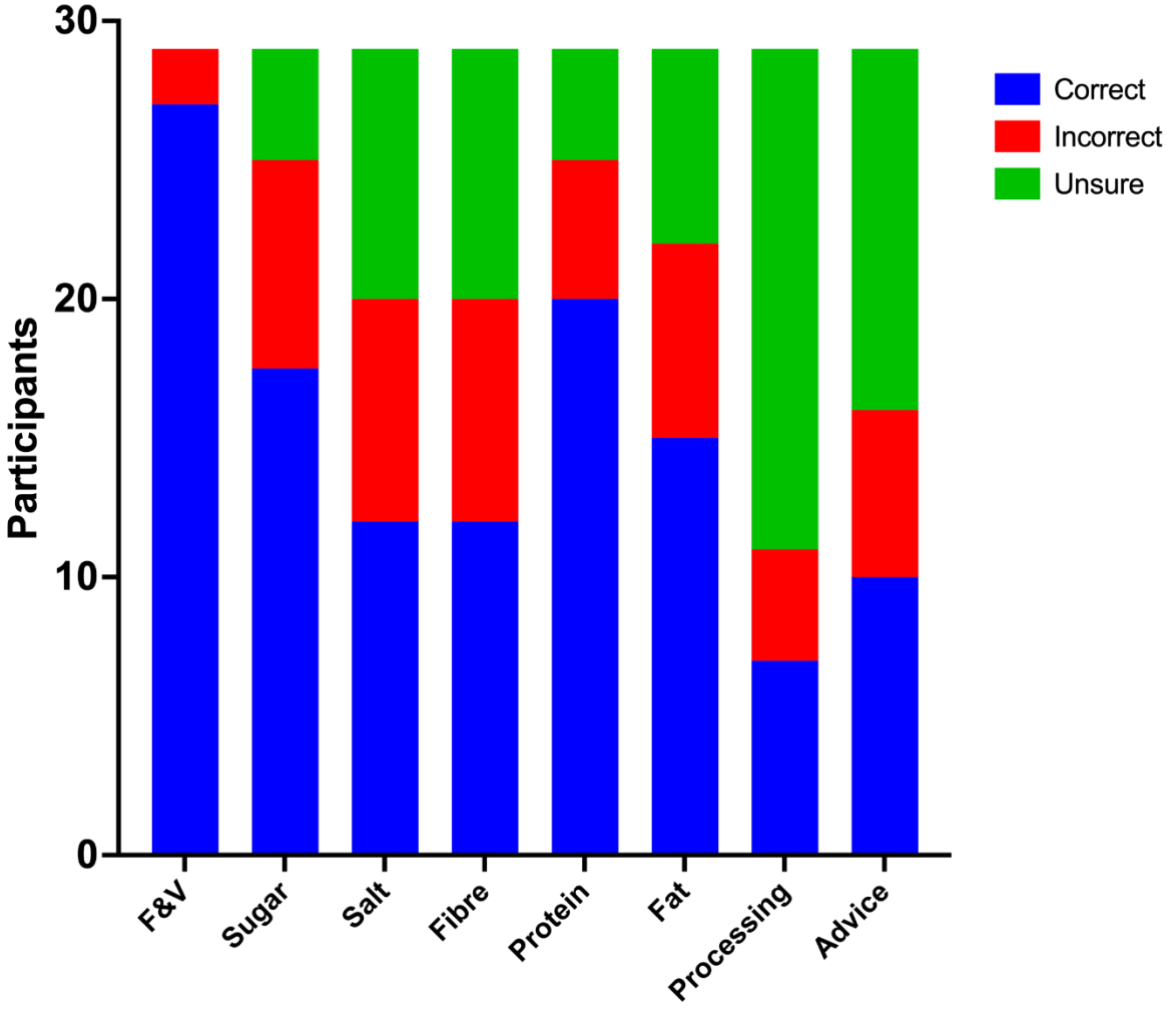


Figure 7.9 Food and drink intake before, during and after hockey sessions within the 7-day period. Fluid included homemade and commercial sports drinks, milk, or water. Carbohydrate sources included fruit, fruit smoothies, commercial or homemade carbohydrate sports drinks, gels, jelly sweets, bread and jam, and baked goods (biscuits, fig rolls and malt loaf). Protein sources included milk, a meal containing a protein source, nuts, and cheese.

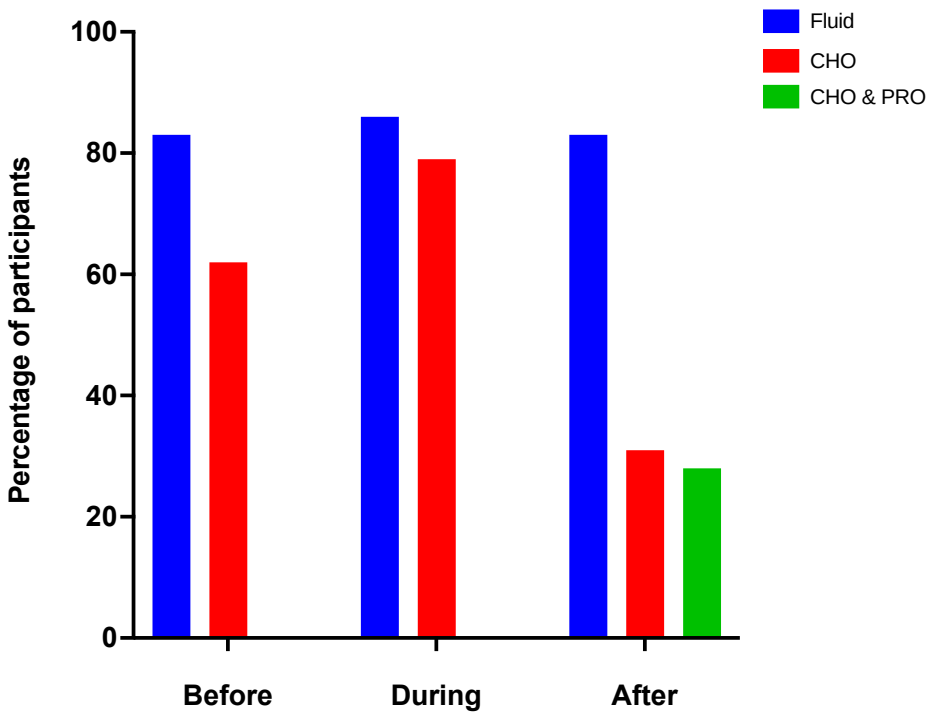


Figure 7.9 shows macronutrient and fluid intake participants recalled having before, during and after playing during the seven-day data collection period. No association was found between the intake of high glycaemic index carbohydrates before, during or after the match and high sugar intake within the food and activity diaries. There was also no association seen between the intake of fluid or macronutrients around the games and either nutrition knowledge or the measure of disrupted eating. The intake of carbohydrate had no influence on the speed of players or the $m \cdot min^{-1}$ covered during the match or

training session but fluid intake during the match was associated with lower recorded $m \cdot min^{-1}$ during the match (p=0.007).

7.5 Discussion

This is the first study to concurrently quantify physical activity, match performance, nutritional intake, nutrition knowledge and eating behaviour in adolescent female hockey players over a 7-day period. Quantifying energy and nutrient needs is necessary in order to build evidence-based strategies to support all athletes but is particularly important during adolescence to ensure optimal growth and physical development (Logue*, et al.*, 2018; Rosenbloom*, et al.*, 2006).

7.5.1 Physical Activity

Physical activity (PAQ-C) scores in the present study were classified as at the higher end of moderate activity (Kolimechkov*, et al.*, 2017) and this is consistent with the PAL estimated from the food and activity diaries (1.6 ± 0.1) and calculated from the measured EE (1.7 ± 0.2, range 1.2 – 2.2). The overall PAQ-C score and the individual measures of activity before school, during morning break, lunch break, after school and at weekends were all higher than previously recorded for school aged girls (Kolimechkov*, et al.*, 2017; Montgomery*, et al.*, 2021; Stewart and Lim, 2017; Voss*, et al.*, 2013) and closer to the values previously recorded for similar aged boys (Kolimechkov*, et al.*, 2017; Voss*, et al.*, 2013). This is in keeping with the findings of Study 4 within this thesis and previous studies which have found that girls taking part in organised sport during adolescence are as active as adolescent boys (Biddle, Whitehead, O'donovan, & Nevill, 2005). The difference between activity levels with gender has been linked to the greater number of boys who will play sport during school breaks and the higher intensity of sports played (Ridgers, Salmon, Parrish, Stanley, & Okely, 2012). A positive association with sports club participation has been found in all adolescents (Telford *et al.*, 2016). Wickel,

Eisenmann, & Welk (2009) found that differences in physical activity between boys and girls were reduced after adjusting for sexual maturity, suggesting that the differences were due to earlier development in girls, no relationship was found between developmental age and activity levels in the present study which may support this finding. Hannon, Parker*, et al.* (2020) found average PAL values of 1.5 ± 0.1 in U12/13 and U15 male adolescent academy footballers over a 2-week period but found a substantial range between individuals (1.3 – 2.2). These PAL in male elite (tier 4) footballers are similar to those calculated in the present study (1.2 – 2.2).

Analysis of hockey training and match load showed that participants in the present study covered comparable total distance (4,283 ± 604 m) to those recorded in female England International U16 (tier 4) (4,962 ± 295 m) (Leslie, 2012) and Canadian International U17 players (tier 3/4) (4,071 ± 1,476 m) (Vescovi, 2016) but the intensity of play and recorded $m \cdot min^{-1}$ were lower (present study 77.7 ± 12 $m \cdot min^{-1}$, U16 England 108 ± 6 $m \cdot min^{-1}$, U17 Canadian 107 ± 9 $m \cdot min^{-1}$). This was comparable to measurements in U16 league games in Study 2 of this thesis, where the distance covered during the match was 4,175.2 ± 1,471.6 m with relative distance 84.6 ± 19.1 $m \cdot min^{-1}$.

In training, participants spent more time in low intensity bands, did less moderate intensity activity and had a lower maximum velocity than during match play. There are no published studies on training intensity in adolescent hockey players but Gabbett (2010) looking at the playing demands of elite (tier 3/4) adult small-sided, game-based training compared to league matches also found more time was spent in low intensity activities and less time in moderate activity bands, concluding that even small-sided games were ineffective training for match demands. It is not clear from this study whether time taken to receive instruction was included (Gabbett, 2010) but as the observed training in the present study included sections working on short corners, and the time

spend by players getting instruction, this is thought to be the main reason for the differences seen.

7.5.2 Energy Balance & Energy Availability

Having an adequate EI to provide for EE both for basic body function and sports performance is a special concern for growing female athletes. In the present study, only 14% participants were in positive EB across both measures of EE, only 24% had adequate EA calculated from hockey EEE on match and training days and 28% were below the low EA threshold, which puts them at increased risk of poor health and injury (Mountjoy, 2018). Only one hockey match and one training session were analysed during the 7-days, but as participants recorded doing an average of 9.4 ± 2.5 (range 6 – 16) hours of organised sport a week, including regular swim training and netball, the low recorded EA should be treated with concern.

Energy deficit calculated using the measured EE (GeneActiv) in the present study was found to be lower in developmentally younger participants, where remaining growth was highest. In European adolescents, the most common APHV, the age at which individuals show the highest growth rate, is between 10.7 and 13.4 yr (Malina*, et al.*, 2004), which would suggest that the participants within the present study (14.3 ± 1.3 yr) would be out of this key growth stage. However, APHV in the present study was 12.6 ± 0.5 yr, higher than previously recorded in young athletes (Malina*, et al.*, 2015) and 51.7% of participants were assessed as late maturing according to longitudinal growth data (Kozieł and Malina, 2018). Calculation of a predicted adult height in the present study, using equations validated by Sherar*, et al.* (2005) showed that mean growth remaining was 3.9 ± 3.5 cm with a range of 0 – 13.7 cm between participants. In total, 90% of the participants in the present study were estimated to be still growing, which should be considered when assessing nutritional needs. Energy requirements add 2 - 5 kcal for every gram of weight

gained during growth (Mirwald*, et al.*, 2002; Torun, 2005) and studies using DLW have found substantially higher than estimated EEs in adolescents (Hannon, Parker*, et al.*, 2020; Torun, 2005). There has been some speculation in the past that female athletes are more likely to be late maturing (Malina*, et al.*, 2015) and the present study would fit in with that assertion. The finding that 90% of participants were still growing adds extra concern to the LEA found.

LEA has been found in female athletes in a wide range of different sports (Logue*, et al.*, 2020) but accurate estimation of the prevalence of LEA is problematic as underreporting of energy intake is common in self-report food diaries (Burrows*, et al.*, 2019). Poslusna*, et al.* (2009) found evidence of misreporting in 69 studies with 32.5% of female subjects being identified as under-reporters. Adolescent girls have been shown to under-report their energy intake by between 20% and 30% regardless of whether self-reported, weighed, or estimated food records are used (Bandini*, et al.*, 2003; Bandini*, et al.*, 1990; Bratteby*, et al.*, 1998; Livingstone*, et al.*, 1992). Adolescent girls are also known to find it harder to maintain focus or motivation to adhere to record keeping over long periods (Livingstone*, et al.*, 2004) and their self-report diaries are often found to be poor or incomplete (Livingstone*, et al.*, 2004). The challenges may be even greater for adolescent athletes due to larger portion sizes and frequent snacking as well as extensive training demands limiting the available time (Magkos and Yannakoulia, 2003).

In the present study, measures were put in place to improve the accuracy of reporting. Guidance was given on how to best estimate portion sizes and it was highlighted that everything that was eaten and drunk should be added. Questions were also included within the questionnaire (Main Study, Appendix B, Q24-25 & 30-33) that allowed the food and activity diaries to be checked for completeness and accuracy. This section was designed to give more information on the foods that are commonly misreported; for example, asking about the type of milk used, whether they usually had spread and what

type of drinks they favoured. These answers were used during analysis to confirm information where detail was missing and double check that all the information was there. For example, if a meal was missing from the food diaries but the individual had said they never skipped meals within the questionnaire then the diary was rejected as incomplete. Despite the care taken and extra information given within the questionnaire, when comparing EI with measured EE (GeneActiv) only 44.8% of the diaries showed good validity (Black, 2000) and the reported deficit should be treated with caution. Underreporting of food and underestimating portion sizes is common when foods are snacks or eaten away from home (Garden, Clark, Whybrow, & Stubbs, 2018; Poppitt, Swann, Black, & Prentice, 1998) and there can also be considerable day-to-day variation particularly when foods are only eaten episodically (Kirkpatrick, Baranowski, Subar, Tooze, & Frongillo, 2019). Adolescents tend to eat out more frequently than other age groups and have higher consumption of snack or fast foods (French*, et al.*, 2001). In the present study, all the participants recorded that they ate a meal out in a restaurant or sports club, had a take-away or a ready meal at least once in the previous week but only three food diaries recorded this detail. It is possible that days reported were selected for 'ease of recording' which impacted the EI recorded.

Reported EI in the present study increased with hours of activity done. Previous studies in female adolescent netball players (13-15 yr) have shown that individuals feel hungrier at the end of training sessions and that EI is increased over the following 48 hours when compared to non-training days (Rumbold, Gibson, Allsop*, et al.*, 2011; Rumbold*, et al.*, 2013). This finding has been questioned, as adult research has found a temporary suppression of appetite following moderate to intense exercise (Thivel and Chaput, 2013). However responses to acute exercise bouts have been found to be highly variable (Thivel *et al.*, 2015) and body composition changes during adolescence are known moderators of appetite-regulated gut hormones (Horner and Lee, 2015). It is unlikely that

the exercise sessions in the present study, 75 -81% of which were at low intensity, were of sufficient intensity to cause appetite suppression.

Mean EI in the present study was 1,791.0 ± 313.3 kcal, a daily deficit of 322.2 kcal to the estimated EE using reported physical activity, and of 533.6 kcal to the measured EE from the GeneActiv wrist bands. There have been no published studies in female adolescent hockey players but female athletes have been found to often eat less than required when they are training and competing (Slater, Brown, Mclay-Cooke, & Black, 2017). Previous research that included adult or college hockey players have found lower than recommended EI (Nutter, 1991; Tilgner and Schiller, 1989; Van Erp-Baart*, et al.*, 1989; Wardenaar*, et al.*, 2017) and research in academy football players shows that young male (Boisseau*, et al.*, 2002; Boisseau*, et al.*, 2007; Briggs, Rumbold*, et al.*, 2015; Iglesias-Gutiérrez*, et al.*, 2005; Leblanc*, et al.*, 2002; Naughton*, et al.*, 2016; Nutter, 1991; Ruiz*, et al.*, 2005; Russell and Pennock, 2011; Tilgner and Schiller, 1989; Van Erp-Baart*, et al.*, 1989; Wardenaar*, et al.*, 2017) and female players (Braun*, et al.*, 2018; Clark*, et al.*, 2003; Gibson*, et al.*, 2011; Parnell*, et al.*, 2016; Reed*, et al.*, 2014) rarely meet their energy requirements in season.

Concerns about weight and body image are strong influences on food choice in athletes, and women are more likely than men to restrict intake of high energy food groups (Wardle *et al.*, 2004). Calculated BF% in the present study was 21.6 ± 3.9%, which is in line with other studies in female adolescent hockey players (Elferink-Gemser*, et al.*, 2007). BF% is often a focus for coaches when assessing athlete performance (Hogstrom*, et al.*, 2012) and as fat mass naturally increases over puberty in female adolescents (Malina and Geithner, 2011), this can be a time when athletes actively work to reduce dietary intake. In the present study, there was no association found between weight, body composition or BMI and reported energy deficit or the calculated measure of disrupted eating, and body composition was unlikely to be the cause of recorded under-eating.

7.5.3 Quality of Dietary intake

Reported breakfast eating within the present study was high, with 97% of participants reporting that they ate breakfast at least 5 times in the last seven days and 56% always eating breakfast at home. Breakfast eating has been linked to better all-round nutrition (Rampersaud*, et al.*, 2005) and also greater daytime and weekend physical activity in adolescents (Briggs*, et al.*, 2017; Corder*, et al.*, 2013; Corder*, et al.*, 2011). Only one participant recorded not eating breakfast on any day within the four-day collected food and activity diaries, but the size of breakfast was low across all participants. Although physically active adolescents are less likely to miss breakfast (Corder*, et al.*, 2011), analysis of the dietary intake in male UK academy footballers during training and match days shows a similar distribution of intake to the present study, with evidence of inadequate breakfast consumption and an uneven distribution of macronutrient intake over the day (Anderson*, et al.*, 2017; Naughton*, et al.*, 2016). Uneven dietary intake and low breakfast intake is also seen in adult elite (tier 4/5) athletes (Gillen*, et al.*, 2017) and trained footballers (tier 2/3/4/5) (García-Rovés*, et al.*, 2014). The International Society of Sports Nutrition Position Stands on nutrient timing and meal frequency emphasises the importance of evenly spreading nutrient intake across the day (Kerksick*, et al.*, 2017; La Bounty*, et al.*, 2011). Naughton*, et al.* (2016) recommended that macronutrient balance and EI could be improved by greater EI at breakfast. As shown in Figure 7.6, EI in the present study is lower in the early hours of the day and an increase of just 200 kcal added to breakfast, would move participants into EB in this timeframe and balance EI more evenly across the day.

Including a good protein source at breakfast is also important (Areta*, et al.*, 2013; Mamerow*, et al.*, 2014). As found in other team sport athletes (Anderson*, et al.*, 2017; Gillen*, et al.*, 2017; Naughton*, et al.*, 2016) protein intake in the present study were heavily weighted towards the end of the day. Traditional protein intake guidelines have

always been provided as g·kg^{-1} body mass, however newer recommendations are given to highlight that muscle adaptation is maximised by ingesting protein spread in meals across the day. (Desbrow*, et al.*, 2014; Potgieter, 2013). The current ACSM recommendation is to consume 0.3 g·kg^{-1} after key exercise sessions and every 3-5 hours over multiple meals (Thomas*, et al.*, 2016). Protein intake in the present study was 1.4 ± 0.3 g·kg^{-1} body mass a day, with intake below the recommended 0.3 g·kg^{-1} in all time frames other than 1701-2000 hours when the evening meal was commonly eaten. Taking the research in female team sport athletes by Wooding*, et al.* (2017) into account intake should ideally be increased to 1.4 – 1.7 g·kg^{-1}·d^{-1} and there would be additional benefit from taking protein after exercise (Mercer*, et al.*, 2020). Only 10% of participants recorded having a protein snack after training or match play and the composition of match tea is uncertain.

Free sugar intake was higher than recommended (7 ± 3% EI), increased with increasing hours of activity (p=0.02) and was positively associated with increasing deficit between reported intake and both estimated (p=0.006) and measured (p=0.001) EE. Sugar sweetened beverages including sports drinks account for 30% of total free sugar intake in UK adolescents (11-18 yr) (Fairchild*, et al.*, 2017) and higher intake of sports drinks is seen in adolescents who do higher levels of moderate to vigorous physical activity (MVPA) (Larson*, et al.*, 2014). If participants in the present study were regularly using sports drink, this would explain this relationship, but sugar sweetened drinks were not regularly reported on the food and activity diaries or within the questionnaires. Most participants reported that water was their drink of choice when thirsty and during sport. Only 6 participants reported using either commercial or homemade sports drinks, juices, or a smoothie before, during or after training or match play.

Saturated fat, sugar, FV and fibre intakes are often used as measures of diet quality (Biltoft-Jensen*, et al.*, 2008; Carvalho*, et al.*, 2014). In the present study, both saturated

fat (14 ± 2% EI) and added sugar intake (7 ± 3% EI) was higher than recommended, with 93% of participants having high saturated fat and 72% having high added sugar intake. FV (3.1 ± 1.4 portions·day^{-1}) and fibre (15.2 ± 4.0 g) intakes were low, with 79% of participants not achieving the recommended 5 FV on any single day, all suggesting low overall diet quality. The National Diet and Nutrition Survey in the UK consistently shows that adolescent (11-18 yr) have the poor diets with low FV consumption (2.8 portions·day^{-1}), and high consumption of saturated fat (12.6% EI) and added sugar (15.2% EI) (NDNS, 2018; NDNS., 2016). Despite some evidence of higher intake than the general population (Crane and Temple, 2015), low FV intakes are regularly found in adolescent athletes (Abbey*, et al.*, 2017; Aerenhouts*, et al.*, 2011; Aerenhouts*, et al.*, 2008; Rosen*, et al.*, 2017; Smith*, et al.*, 2016) and the present study would fit in with these findings. Availability or accessibility of foods are powerful predictors of consumption in adolescents (Cook*, et al.*, 2015) and FV intake has been linked to availability, but in the present study 100% of participants reported that FV were easily available both at home and school suggesting this is not a factor.

Adequate EI providing 'fuel for the work required' is a key component of sports nutrition (Impey*, et al.*, 2018) and poor carbohydrate availability would be expected to influence match and training performance (Burke*, et al.*, 2011; Impey*, et al.*, 2018; Jeukendrup, 2014). However, neither the total distance covered or relative distance (m·min^{-1}) during the match were linked to any measure of macronutrient intake, EB or EA, and comparison of the detail from the questionnaire on food choices before, during and after matches found no association between the intake of food or carbohydrate containing drinks and the distance, relative distance, or speed of participants in the present study. Carbohydrate intake should be highly personalised, focusing on activity demands. Current advice for young athletes is to have between 3 and 10 g·kg^{-1}·d^{-1} (Desbrow, 2021b; Hannon, Close*, et al.*, 2020; Naughton*, et al.*, 2016) focusing on adapting intake to the training or competition load on each day (Reguant-Closa*, et al.*, 2019).

Carbohydrate intake in the present study was 4.4 ± 1.2 $g \cdot kg^{-1} \cdot d^{-1,}$ which was within the recommended range, but was only 49% of total EI, which is lower than the 50-60% that would be recommended in active adolescents (Desbrow*, et al.*, 2014). Exogenous sources of carbohydrate are thought to be of greater importance in young athletes due to lower potential glycogen stores (Ekblom, 1986; Phillips*, et al.*, 2010) and the advice during moderate-to-high intensity exercise is to consume 30 – 60 $g \cdot h^{-1}$. Intake of carbohydrate before and during the game was common with 62% of participants recording that they had some carbohydrate before matches and 79% during games.

Self-reported fluid intake during a match was associated with lower recorded relative distances ($m \cdot min^{-1}$). Macleod and Sunderland (2009) assessing sweat loss and hydration practices in elite (tier 4/5) adult female hockey players concluded that there are large inter-individual differences in sweat losses and drinking habits in players but that players who had regular access to fluid because of regular substitutions drank more. Although there is considerable research that shows that adolescent athletes often arrive at training or matches hypo hydrated (Arnaoutis*, et al.*, 2015) and that poor fluid balance produces a decrement to both physical (Ali, Gardiner, Foskett, & Gant, 2011; Nuccio, Barnes, Carter, & Baker, 2017) and skill performance (Baker, Dougherty, Chow, & Kenney, 2007; Nuccio*, et al.*, 2017) in team sport athletes, it is more likely in the present study that weaker or less fit players were substituted more often and so had greater opportunity to drink.

7.5.4 Nutrition knowledge

Higher nutritional knowledge has been found to improve diet quality (Wardle*, et al.*, 2000). In the present study, participants scored 27.5% on the questions taken from the GNKQ (Parmenter and Wardle, 1999). The highest scoring questions were on FV recommendations where 86% of participants gave the correct answer and protein, with

69% being correct. The weakest questions were on food processing (24%) and current nutrition advice (34%). Abdollahi *et al.* (2021) using a selection of questions from the GNKQ to assess the effectiveness of a nutrition education intervention in adolescent school children (13.2 ± 1.2 yr) in the UK measured a baseline score of 51% across all participants and Portuguese adolescents (age 12-14 yr) scored 54% (Ferro-Lebres, Moreira, & Ribeiro, 2014) suggesting that the knowledge of the participants in the present study was low. As in the present study Abdollahi*, et al.* (2021) found the strongest questions were those on FV consumption and protein.

The low score on the GNKQ questions in the present study should be seen as a concern, as a lack of nutrition knowledge is one of the main causes of inadequate dietary behaviour in athletic populations (Spronk, Heaney, Prvan, & O'connor, 2015) and increasing nutrition knowledge has been shown to be important in supporting healthier eating habits (Worsley, 2002). However, it was noted that several of the questionnaires were answered with a greater number of 'not sure' selections in the final section and it is possible that as these were the last questions participants did not complete the final questions carefully. Due to the negative mark scheme used this could have over or under-estimated their true knowledge.

There were several key limitations within the study. Data protection concerns had prevented the use of photographic food diaries, which have been consistently found to improve reporting in adolescence (Costello*, et al.*, 2017) and despite both parent or guardian checking and additional information from the questionnaire, the validity when compared to the measured physical activity was poor. Measured physical activity (GeneAvtiv) was higher than estimated from the reported activity given within the food and activity diaries and reported in the PAQ-C questionnaire. However, due to the importance of the cup game played within the study week, extra training sessions were added that were not within the normal timetable. This may have distorted measured

physical activity higher during the measured week but not have influenced dietary behaviour. Dietary intake in children and adolescents are often more influenced by family meals and the school menu than by personal choice and it is harder for them to adapt to energy demands (Story*, et al.*, 2002). The questionnaire given on the final day of the study was a rich source of supplementary information, allowing better analysis of both physical activity and dietary intake. The questionnaire was constructed from three validated questionnaires (Goodyer*, et al.*, 2010; Kowalski*, et al.*, 1997; Parmenter and Wardle, 1999) but to keep the questionnaire to a manageable size, not all the questions were included which made comparison between studies more difficult. However, there was some indication that participants still found the survey too long and it was possible that some of the final questions were not as carefully answered. Previous research has demonstrated a negative effect of questionnaire length on both response rates and data quality, including on the rate of 'I don't Know' answers (Revilla and Ochoa, 2017). Future studies should investigate doing several shorter surveys to enhance answer quality.

To conclude, this study has concurrently quantified physical activity and dietary behaviour in adolescent hockey players to assess nutritional adequacy over a 7-day period during the hockey season. EI in the present study was low and PAL showed that participants were at the high end of moderately active, with some individuals doing more activity than would be recommended for their age (Jayanthi and Dugas, 2017). The low EI and high EE resulted in periods of LEA on both training and match days. Although underreporting is common this should be seen as a concern as both chronic low EI, and poor at the time EA in adolescent girls can result in impaired growth and maturation, increased injury risk and health implications later in life (Loucks*, et al.*, 2011).

Diet quality, assessed by intakes of saturated fat, added sugar, fibre and fruit and vegetables was poor. Total fat intake was higher and carbohydrate intake lower than would be recommended as a percentage of total energy consumption and in gram terms

for this level of activity and all macronutrient intake was poorly distributed across the day. Current advice emphasises the importance of evenly spreading nutrient intake across the day and it is particularly important for athletic performance that carbohydrate (Impey*, et al.*, 2018) and protein (Jager*, et al.*, 2017) is readily available at the time it is needed. The adolescent hockey players in the present study were covering similar distances in matches to adult hockey games, but the intensity of play was lower. Fuelling training and matches adequately and focusing on practical recovery strategies would be recommended.

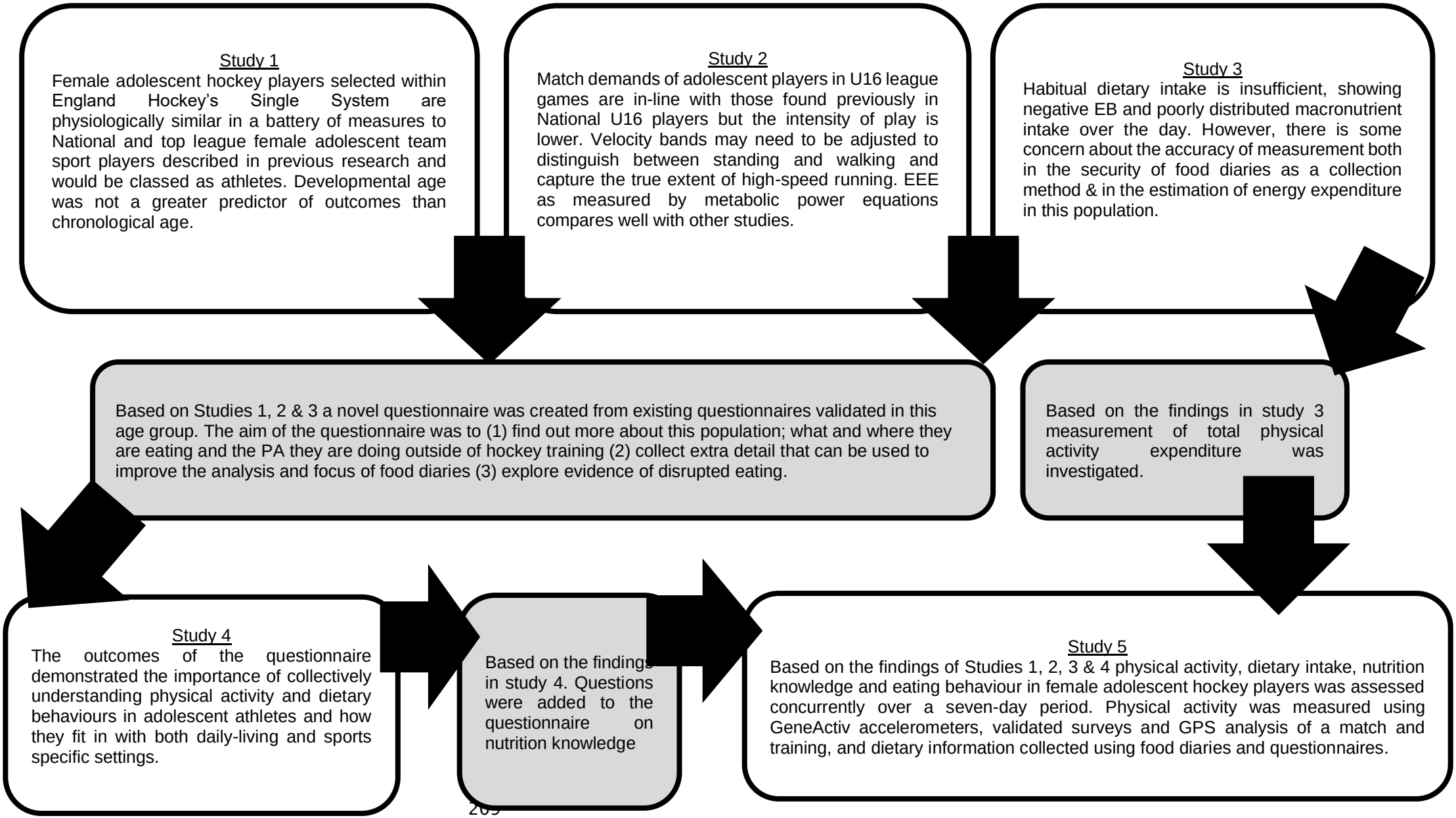
8. General discussion

The aim of this chapter is to collectively bring together and evaluate the information presented in this thesis. This will enable discussion regarding how the novel research undertaken can further the understanding adolescent female hockey players diets, nutritional needs, and physical activity. Particular consideration will be made in section 8.6 on how the research presented here can be used to inform applied practice and future research requirements.

8.1 Achievement of thesis aims and objectives

There has been little research conducted to examine the physiological characteristics, level of sports participation, dietary intake, and EE in female adolescent athletes and none that examines these areas within hockey or looks at the demands of hockey training or competition in adolescent girls. The hypothesis for the thesis was that female adolescent hockey players at the bottom of the England Hockey Single System are fitter, have higher EE and PA levels than population normative data, that the demands of playing competitive hockey are high and that adolescent girls are not adequately compensating for this with their current dietary intake. This hypothesis was examined through a series of field-based studies outlined in chapters 3, 4, 5, 6 and 7. Figure 8.1 illustrates how the results from Studies 1-5 provide new information to improve the understanding of the physiology, nutrition, and training demands within female adolescent hockey players.

Figure 8.1 Overview of studies 1-5 within the thesis.



Study 1 described the physical ability and skill level of adolescent female hockey players using recognised sprint, strength and dribble tests and investigated the importance of developmental age as a predictor of performance in female adolescent athletes. The results of these tests showed that all the measurements were in line with similar studies in elite (tier 4/5) or sub-elite (tier 2/3) female adolescent team sport players and they also demonstrated above average hockey skill and fitness in this group. The IOC consensus statement on training the elite child athlete defines a child athlete as "one who has superior athletic talent, undergoes specialist training, receives expert coaching and is exposed to early competition" (Mountjoy*, et al.*, 2008) and from this definition this group of female adolescent hockey players, involved in competitive club or school sport and selected for specialist training would be classed as athletes and so likely to require specialist support. During adolescence, care should be taken that young athletes get adequate energy to meet growth and developmental needs in addition to the nutrient demands associated with general physical activity, athletic training, and competition, (Aerenhouts*, et al.*, 2011).

In Study 1 strength, speed, and power were found to increase with age. It had been hypothesised that due to hormonal and muscular changes over puberty that growth and performance measures would be more closely linked to developmental age than the chronological age of participants. However, although there was a trend that suggested a higher association of developmental age than chronological age with grip strength, leg power and slalom dribble score, the difference was small and not significant.

In Study 2 and 5 Catapult GPS were used to analyse the activity profile and calculate EEE in female adolescent hockey players in training, U16 league games and a cup game. These are the first studies to describe physical performance in female adolescent hockey players and aimed to provide normative and comparative data to inform coaching and training strategies, as well as allow better provision of nutrition support. There was

a wide difference in the playing ability across all the players monitored. In all matches, the average time on the pitch was similar to previous studies in female university and female adult club hockey players (Leslie, 2012; Vescovi and Frayne, 2015; Vinson*, et al.*, 2018) but the time played varied between players from <40% to 100% of game time. Total distances covered were comparable to international female U16 and U17 teams, (Leslie, 2012; Vescovi and Frayne, 2015) but the $m \cdot min^{-1}$ of pitch time were lower. International U16s and U17 female hockey players averaging 107-108 $m \cdot min^{-1}$ (Leslie, 2012; Vescovi and Frayne, 2015) compared to 77-85 $m \cdot min^{-1}$ in this age group. There were a range of performances from 46 to 114 $m \cdot min^{-1}$ with stronger players playing at a comparable intensity to that seen in the elite game. Increasing match intensity and $m \cdot min^{-1}$ should be the aim of adolescent players and coaches as they prepare players who aspire to play at higher levels of the game.

Across all sessions, 97-98% of pitch time was completed in low or medium velocity movement bands and 75 - 79% standing or walking. The cup match played in Study 5 measured higher moderate intensity activity than the U16 League matches in Study 2 ($p=0.03$) but no difference in the amount of high intensity activity was seen between matches. Vinson*, et al.* (2018) and White and Macfarlane (2013) found that the standard of the opposition influenced the distance and playing intensity in female adult hockey players, with players working harder against more highly-ranked opponents. The games in Study 2 were chosen to be against clubs of similar league position whereas the Cup games were to qualify for finals which may have explained this difference. The amount of low and moderate intensity activity in matches was comparable with previous studies (Gabbett, 2010; Leslie, 2012; Macleod*, et al.*, 2007; Macutkiewicz and Sunderland, 2011; Mcguinness*, et al.*, 2019) but the amount of low activity, standing or walking was considerably higher and this has previously been identified as a key difference between elite and non- elite games (Gabbett, 2010).

Focusing on distance covered and intensity of play fails to fully account for the energy cost of key features of team sport match-play; accelerations, decelerations, jumps, turns, dribbling and contact usually being classified as low-speed activity despite evoking high physiological load (Beenham*, et al.*, 2017; Osgnach*, et al.*, 2010). The use of metabolic power to calculate an estimate of EEE includes this movement and is thought to give an accurate assessment of the cost of intermittent exercise (Di Prampero and Osgnach, 2018; Polglaze*, et al.*, 2016). EEE during the matches in Study 5 was 386 kcals and in Study 2 was 452 kcal per game, comparable with the values measured in U17 (314 kcal) and U21 (413 kcal) female international players (Vescovi, 2016), but lower than measured in international male players (27.5 ± 3.1 yr) , who were found to expend 585 kcal per match (Polglaze*, et al.*, 2017). The dietary intake of participants in Study 3 was not collected, but within Study 5 EEE was used to calculate estimates of at the time EA. In Study 5, only 24% had adequate estimated EA on match and training days and 28% were below the LEA threshold, which puts them at increased risk of poor health and injury (Mountjoy, 2018). As only one hockey match and one training session were analysed and participants recorded a range of hours of participation in organised sport (6 – 16 h over the previous 7-days) the low recorded EA should be treated with concern. This is particularly the case as 51.7% of participants were identified as late developers and 90% as still growing, making good EA even more critical.

The aim of Study 3 was to document the in-season dietary intake and physical activity of the same group of female adolescent hockey players as monitored in Study 1 and 2, to assess eating habits, dietary adequacy, and the distribution of energy and macronutrient intakes over the day. The objective of studies 1 - 3 was to assess the current adequacy of habitual nutritional intake in this adolescent hockey players, using the information from studies 1 and 2 to inform the choice of activity level to predict EE. EE was estimated using Oxford Equations (Henry, 2005) to calculate BMR and the physical activity level was also checked against self-reported activity on the food and activity diaries

themselves. Study 3 is the first to quantify the estimated EE and dietary intake in female adolescent hockey players within the playing season. Only 25% of participants were in positive EB, with an average deficit of 158 ± 284 $kcal \cdot d^{-1}$. Low reported EI is common in athletes and previous studies have shown that EI in female hockey players is often below that recommended for EB (Nutter, 1991; Tilgner and Schiller, 1989; Van Erp-Baart*, et al.*, 1989). Negative EB has also been found in a wide variety of other female adolescent athletes. (Baker*, et al.*, 2013; Beals, 2002; Burke, Desbrow, & Spriet, 2013; Clark*, et al.*, 2003; Gibson*, et al.*, 2011; Mullinix*, et al.*, 2003; Papadopoulou*, et al.*, 2002).

Study 3 also found poor macronutrient balance, with lower carbohydrate (46 ± 7%) and higher fat (34 ± 8%) percentages than recommended for adolescent athletes (Desbrow, 2021a; Desbrow*, et al.*, 2018). As confirmed in Studies 2 and 5, adolescent hockey is a high intensity intermittent team sport, making carbohydrate an important fuel source, the amounts and timings of which can be manipulated to promote high availability for specific training sessions or supplemented during training or competition (Thomas*, et al.*, 2016). Study 3 did not look at the distribution of carbohydrate intake compared to the timing of activity, but intake was found to be evenly distributed over the day. Protein intake was ~1.6 $g \cdot kg^{-1} \cdot d^{-1}$ in line with recommendations based on nitrogen balance studies in mixed gender adolescent athletes (Aerenhouts*, et al.*, 2013). However, as found in other studies in adult and young athletes, the distribution of protein intake was sub-optimal and skewed towards the end of the day (Figure 5.1). (Anderson*, et al.*, 2017; Gillen*, et al.*, 2017; Naughton*, et al.*, 2016). The current ACSM recommendation is to consume 0.3 $g \cdot kg^{-1}$ after key exercise sessions and every 3-5 hours over multiple meals (Thomas*, et al.*, 2016).

Reported breakfast eating in Study 3, 4 and 5 was strong and in Studies 4 and 5 participants recorded that they predominantly ate breakfast at home. Breakfast eating has been linked to better all-round nutrition (Rampersaud*, et al.*, 2005) but as identified

in the food diaries in Study 3 and 5, research in male adolescent footballers has found that breakfast consumption is often inadequate and can lead to uneven distribution of macronutrient intake over the day (Anderson*, et al.*, 2017; Naughton*, et al.*, 2016). Due to the popularity of breakfast in this population, breakfast might be seen as a good platform to use to encourage better eating behaviours. Adding 0.3 $g \cdot kg^{-1}$ protein to breakfast, including protein within a morning snack and lowering intake in the evening would both improve EB and help to rebalance macronutrient intake more evenly across the day.

The food and activity diaries used in Study 3 provided a detailed snapshot of the behaviour of this group of adolescent athletes over a 4-day period, but it is important to view this within the context of all the demands and constraints that form the complex nature of adolescent athlete's lives. The aim of Study 4 was to obtain additional information about the physical activity levels, sport participation and eating behaviour of a wider group of female adolescent hockey players, to improve knowledge about the key factors influencing nutritional adequacy in this age group. To do this an online survey was constructed using questions from three previously validated questionnaires and a Pilot Study was used to identify weaknesses and check feasibility.

Nutrition is an important component of the support for adolescent athletes contributing to both their health and athletic performance. Adolescence is an age of increased growth and development, and careful consideration of nutrition needs is required to meet these demands (Desbrow*, et al.*, 2019; Hannon, Close*, et al.*, 2020; Hannon, Parker*, et al.*, 2020) and as it is a time when lifetime habits develop, it is a priority to introduce good practice at this time (Winpenny, Penney, Corder, White, & Van Sluijs, 2017). In Study 4, the questionnaire found 72% of respondents ate breakfast at home every day and 74% recorded that they ate a cooked lunch at school, which would both indicate nutritional stability. However, there was evidence that sports participation was influencing dietary

intake with 28% of respondents eating their evening meal in a sports venue at least once a week, 6% having a packed lunch 6-7 times a week and 23% reporting having pack lunches provided by the school at least once a week, which are commonly provided when individuals are required to miss lunch due to travelling or preparing for sporting fixtures. The commitment of playing for a club and school was linked to an increase in the calculated measure of disrupted eating. Time constraints associated with training or competition have been identified in previous studies as making achieving an adequate and balanced diet more difficult (Smith*, et al.*, 2015). Knowledge of the current guidance and the availability of good choices are the key factors influencing food intake (Bentley*, et al.*, 2020; Birkenhead and Slater, 2015) and the correct foods need to be accessible if they are to be made part of a balanced diet (Cook*, et al.*, 2015). Higher consumption of fast or snack foods is particularly common in adolescence (French*, et al.*, 2001; Thomas*, et al.*, 2012) and can result in adolescent athletes eating more high fat, high sugar snacks replacing meals (Squire, 2013). Within the food and activity diaries collected in Study 3, the intake of saturated fat (13 ± 3% EI) and sugar (11 ± 5% EI) were higher than recommended. Increased consumption of high-energy-dense-foods has been found in other studies and been identified as occasionally necessary to allow adolescent athletes to achieve their higher-than-normal energy needs (Burrows, Harries, Williams, Lum, & Callister, 2016).

Study 4 also investigated the dietary intake around matches and the use of sports nutrition. Although the food choices before, during and after the match included those that would be recommended, there was considerable individual variation. Previous studies have found sugar sweetened beverages including sports drinks account for 30% of total free sugar intake in UK adolescents (11-18 yr) (Fairchild*, et al.*, 2017) but they were not commonly used in this population, 22% did not eat at all in preparation for a game and 34% chose foods that would not be recommended due to being high energy density, high glycaemic index, high fibre, or high fat. The National Diet and Nutrition

Survey in the UK consistently shows that adolescent have the poor diets, with low FV consumption, and high consumption of saturated fat and added sugar (NDNS, 2018; NDNS., 2016). These broader population findings are reflected in the dietary intakes in adolescent hockey players found in both Study 3 and 5. In Study 4 and 5, just under a quarter of participants had a packed lunch either prepared at home or by the school over 5 times a week. The content of pack lunches would be a second area where eating behaviour could be improved. There has been little research specifically in adolescents but studies in younger children have found that the most popular foods consumed by children having a packed lunch at school are high in sugar, are often highly processed, and lack B-vitamins, protein and fibre (Arcan*, et al.*, 2007; Summerbell*, et al.*, 1995). Higher consumption of fast or snack foods is common during adolescence (French*, et al.*, 2001; Thomas*, et al.*, 2012) and high consumption can replace meals (Squire, 2013). Training sessions within Performance Centres and Junior Academies at weekend are regularly for whole days and players are asked to bring a packed lunch, and many of the selection camps and competitions involve multiple games over a day. Education on the content of the foods taken to these days and the relevance of different nutrients eaten around sports training and competition would not only improve the composition of this part of the diet but would also feed into allowing better fuelling for and recovery from sports training or competition.

A lack of nutrition knowledge has been identified as a main cause of inadequate dietary behaviour in athletic populations (Spronk*, et al.*, 2015), and increasing nutrition knowledge has been shown to be important in supporting healthier eating habits (Wardle*, et al.*, 2000; Worsley, 2002). In Study 5, the questions included on nutrition knowledge were poorly answered. This should be seen as a concern but also as an opportunity and putting an education program into effect would be a third way to improve the dietary intake in this group.

The results of the physical activity questions within Study 4 identified that respondents were frequently playing multiple sports, often at county level or higher. A total of 41% also played for more than one hockey team and 28% played for both club and school teams. This is vital information for practitioners working with this group as focusing on any one sport or team will underestimate the overall training load and energy demands. In young athletes, physical activity EE is often the greatest contributor to TEE (Hannon, Parker*, et al.*, 2020; Silva*, et al.*, 2013) and coaches should be aware of the total level of training being done. There are no previous studies on total physical activity in adolescent hockey players or that have investigated how the level of organised training influences total physical activity over a week. In keeping with the high recorded sport participation, the questionnaire in Study 4 showed participants were classed at the high end of moderately active and more active than previous studies in adolescent girls for evenings and weekend activity (Kolimechkov*, et al.*, 2017; Voss*, et al.*, 2013).

To assess whether the total level of physical activity being done in this population was as high as indicated by the food and activity diaries in Study 3 and the questionnaires in Study 4, the final study - Study 5 added the measurement of total physical activity, using GeneActiv accelerometers, to allow more accurate calculation of TEE and PAL. Combining the collection of measured physical activity, training/match duration and intensity, and dietary intake data giving a rich depth of detail to better qualify the energy and nutrient needs in this group. This resource can then be used to give context to build stronger evidence-based strategies and improve support for female adolescents. Similar to Study 4, the participants in Study 5 had a PAQ-C score that classified their physical activity at the high end of moderate (Kolimechkov*, et al.*, 2017) and was consistent with the physical activity levels estimated from the food and activity diaries (1.6 ± 0.1) and calculated from the measured EE (1.7 ± 0.2, range 1.2 – 2.2). Hannon, Parker*, et al.* (2020) used DLW to investigate EE in male adolescent academy footballers, and as found in this study calculated a substantial range of PAL values (~1.3 – 2.2) between

individuals. It would be expected that physical activity levels in talented top academy male footballers would be higher than a school team of female adolescent hockey players and the high mean PAL value and range seen should be investigated further, especially as the BMR used in the present study was estimated. However, it is possible that the academy players were exhibiting some compensatory behaviour. Weiler*, et al.* (2015) found that 79% of post-training time in adult English Premier League footballers was spent in sedentary activity, and low levels of non-training activity has also been identified in elite (tier 3/4) male rowers (Sperlich*, et al.*, 2017). Similar compensatory sedentary behaviours may explain the comparison in male adolescent footballers. School aged, school-based athletes must divide their time between training and studying and the amount of sedentary behaviour may not be in the young athlete's control. In a systematic review of international research by Arundell, Fletcher, Salmon, Veitch, & Hinkley (2016), 54% of after-school time in children and adolescents was found to be spent in non-screen based sedentary behaviours; motorised transport, homework and reading. It is possible that adolescents in regular school but playing more than one competitive sport will be spending more after school time being active. In both Study 4 and Study 5, the PAQ-C score and the individual measures in each timeframe were higher than previously recorded for school aged girls (Kolimechkov*, et al.*, 2017; Montgomery*, et al.*, 2021; Stewart and Lim, 2017; Voss*, et al.*, 2013) and closer to the values previously recorded for similar aged boys (Kolimechkov*, et al.*, 2017; Voss*, et al.*, 2013). This is in keeping with previous studies which have found that girls taking part in organised sport during adolescence are as active as adolescent boys (Biddle*, et al.*, 2005).

8.2 Discussion of methodological approach

This was the first study that has looked at physical activity, movement profiles, energy demand, nutritional intake, eating behaviour and nutrition knowledge in female

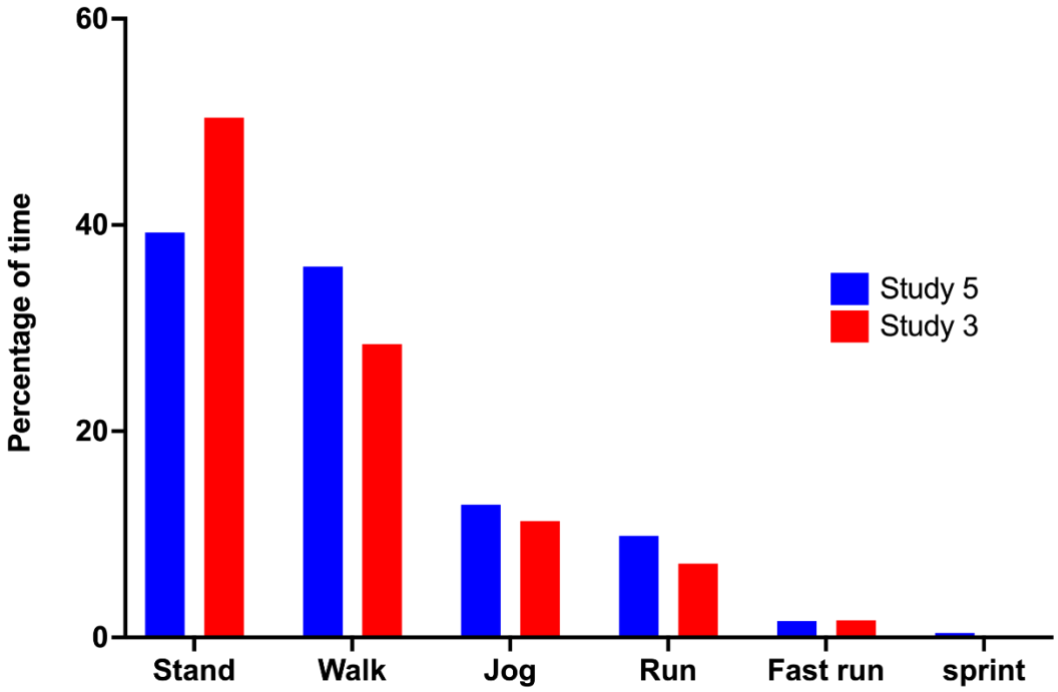
adolescent, trained and highly trained hockey players (tier 2/3), and provides a depth of useful information on the nutritional adequacy of adolescent hockey players diets, and how these match competition and training demands.

One of the strengths of this research was its tight recruitment criteria, ensuring that all participants were classified as 'trained' and of a standard to be selected for the early stages of the England Hockey Single System, but this was not without difficulties. Despite good buy-in from local and regional hockey coaches, the logistics of getting parental agreement and individuals to testing to complete the data collection required resulted in smaller than expected participant numbers, particularly for Study 1 and 2.

One of the primary aims of Study 1 was to investigate whether developmental age was an important measure when looking at and comparing the performance of female adolescent hockey players, developmental age being expected to have a greater relationship with performance measures than chronological age. HGS, Peak anaerobic leg power and dribble speed were all more strongly correlated to developmental age than chronological age, but the difference was small. The low number of participants increases the likelihood that this difference is down to chance and a greater participant number would strengthen the certainty of the trends seen and may also have increased the strength of the relationship. Within Study 1 all but one participant was classified as average maturating with a tight distribution of APHV. A greater number of participants with a wider range of developmental ages may have emphasised the links between developmental age and physical development. In Study 2, no difference was found in the movement profiles of different playing positions. It is possible that no differences in movement profiles are seen in this age group, as tactical positions are less tightly held and players regularly move between positions within games, but the small sample size makes it more likely that this outcome was due to chance.

In Study 2, the velocity bands used to assess the intensity of movement were chosen to map with those used by Leslie (2012) in female and adolescent hockey players. The percentage of time in low and medium intensity bands was found to be high and amount of time spent standing was substantially higher than in other studies (Gabbett, 2010; Leslie, 2012; Macutkiewicz and Sunderland, 2011; Mcguinness*, et al.*, 2019). The lower velocity bands in Study 2 were in keeping with the available research on movement speeds in children and adolescents (Schwartz*, et al.*, 2008; Waters*, et al.*, 1988) but within a game setting where movement may be multidirectional, it was thought that it may be more appropriate to use a lower velocity description of standing. In Study 5, the low intensity bands were adjusted to match those used by Macutkiewicz and Sunderland (2011). This change gave a better distinction between walking and standing as shown in Figure 8.2 and these bands should be adopted for future research in female adolescent players. However, the high velocity bands, particularly the cut off between fast run and sprint continues to be a concern and appropriate cut offs should be investigated further. The use of individual speed bands in the present study was rejected, as using set descriptors allows better comparison between studies, however measuring participants repeat sprint speeds and using these to set a realistic upper velocity band would have been beneficial. From the present research, the small number of recorded sprints across both Study 2 and 5 (figure 8.2) suggests that the velocity cut off used for sprinting (>5.31 $m \cdot s^{-1}$) was too high for repeated sprints.

Figure 8.2 GPS percentage time spent in the velocity bands assigned for standing, walking, jogging, running, fast running, and sprinting during competitive match play. Velocity bands were set as 0-0.83 m·s^{-1}, 0.86-1.67 m·s^{-1}, 1.69-2.77 m·s^{-1}, 2.80-4.02 m·s^{-1}, 4.05-5.28 m·s^{-1} and >5.31 in Study 2 but in the present study the lower bands were adjusted to give a narrower definition of standing as 0-0.17 m·s^{-1} and walking given as 0.19-1.67 m·s^{-1}. All higher intensity bands were left unchanged.



The use of metabolic power to measure EEE is not yet been validated within hockey. Study 3 and 5 similar to the research by Vescovi (2016) and Polglaze*, et al.* (2017) found that the energy cost of hockey games is lower than other team sports (Coutts*, et al.*, 2015; Kempton*, et al.*, 2015; Osgnach*, et al.*, 2010). This may be explained by the shorter games, smaller playing area and unlimited substitution within hockey as concluded by Polglaze*, et al.* (2017) but some caution should be given, as the current model of

metabolic power may underestimate the cost of the bent stance required when dribbling a ball. In female adult games, Mcmahon and Kennedy (2019) and Mcguinness*, et al.* (2018) have identified higher recorded meter per minute distances and high recorded heart rates for intensity of play than other team sports.

In Study 3, the detail collected within the food and activity diaries collected was good, with the timing of meals and size of food portions given and meals broken down into the individual components. The ability to question participants on their intake, also allowed missing detail to be added. Much of the missing detail required was the same across all participants and in Study 5 questions on these areas were added into the questionnaire given to all participants (Main Study, Appendix B, Q24-25 & 31-33). This was thought to help with the interpretation of the diaries. However, there was still concern that there was underreporting of intake in both studies and some evidence that participants had selected the days that they included to be "more normal", making the days not truly representative of their habitual diet or the way their sport or other commitments were impacting their nutritional intake. In Study 5, the questionnaire was given to the participants on the last day of the 7-day collection period and was separate from the food and activity diaries. The questions added to the questionnaire on the types of foods eaten and meal-time habits were adapted from questions included in the ROOTs food diary (Corder*, et al.*, 2013; Goodyer, 2005) and including these with the food and activity diary, as in the original may promote more accurate accounting. Photographic food diaries have been consistently found to improve reporting in adolescent athletes (Costello*, et al.*, 2017) but data protection concerns had prevented their use in Studies 3 and 5.

The questionnaire used in Study 4 and 5 provided a rich source of supplementary information allowing for better analysis of both physical activity and dietary intake. Questions used came from 4 independently validated questionnaires but not all the questions were included to reduce the questionnaire to a manageable size. Previous

studies have demonstrated a negative effect of questionnaire length on response rates and data quality. Revilla and Ochoa (2017) investigating the preferred length of surveys in an adult population found the maximum tolerated length was 20 minutes, which was the estimated length of the Survey Monkey Questionnaire used (Appendix B). However, as parts of each survey were not included it made comparison with previous studies more difficult. The development of a specifically designed physical activity and dietary behaviour questionnaire that is reliable and validated for use in this age group would strengthen the conclusions of future studies.

In studies 2-5, feedback on GPS data and nutritional intake was given to participants and coaches within 7-days of data collection, with the aim of better informing coaching practice and player performance. This had been agreed within the ethics application and with coaches at the time of recruitment. This commitment prevented secondary data collection from the same participants or groups as they could no longer be considered independent. This was a particular problem with the performance analysis of hockey games as players with weaker statistics were reluctant to wear a GPS monitor in subsequent games or training. To eliminate bias within the current thesis data was only collected from individuals once but in future studies it is recommended that feedback to young participants is limited until the end of data collection if possible.

Considerably less is known about female athletes dietary intakes and sports related requirements than for male athletes (Devries and Jakobi, 2021), and the majority of research continues to use predominantly male participants. Due to the recognised hormonal influences on triglyceride storage and metabolism (Beaudry and Devries, 2019) collecting data on the timing of menarche and the phase of individual cycles was discussed. However, due to the aim of the thesis being to provide evidence to inform practice and as teams within this age-group will have a variety of individuals at different stages of development, it was not felt that it was important at this time. However, in future

research it would be interesting to have this information and particularly detail on the stability of individual hormonal cycles and symptoms, as these details may be important when giving personalised advice.

8.3 Recommendations of future research

The data collected across Studies 1-5 gives a rich source of information to improve practice in adolescent team sports and for all practitioners working with this age group. However, there are still very few studies that have been completed in adolescent female athletes and several further research areas are highlighted by the information found. As eating behaviour is key when looking at nutritional adequacy and when designing interventions to improve intake, the development and validation of an eating behaviour questionnaire, with a similar structure to the PAQ-C would be beneficial for practitioners. The main limitation of using self-report surveys is that individuals rarely accurately recall all the detail needed and children and adolescents regularly over as well as under-report behaviours. Ranking answers goes some way to controlling for these difficulties and may be a useful approach.

The use of metabolic power to estimate the energy expenditure is a useful tool to overcome some of the challenges of measuring energy needs for intermittent sports and for adolescent athletes at a time when proper fuelling of activity is key for wellbeing as well as performance. Validating the metabolic power calculations proposed by Di Prampero*, et al.* (2005) for hockey and for use in adolescents across a variety of team sports would open up this method for wider use.

Hannon, Parker*, et al.* (2020) measuring the energy expenditure in adolescent male academy football players found higher energy expenditure than predicted, with both higher physical activity levels and higher measured resting metabolic rates. The poor

prediction by existing equations prompted Hannon, Parker*, et al.* (2020) to create new equations for male academy players. In the current study basal metabolic rate was estimated using predictive equations. Oxford Equations were chosen because of the large underlying data base and their use by both the WHO and SACN. However, Oxford Equations have not been specifically validated for a female athletic or adolescent population. Reale*, et al.* (2020) developed new equations specifically for use in athletic adolescent populations but these have not been validated outside their own study. Looking at these and other predictive equations in adolescent female athlete populations to assess their validity and reliability would help practitioners to estimate energy needs as accurately as possible.

Studies 1-5 collected great depth of detail about the behaviours, diet, and activity in adolescent female athletes with which to inform future practise. The usefulness of this information can however only be assessed if it can be successfully used in the field to improve athletes' dietary behaviour, sports performance, and wellbeing. Using the information collected in Study 5 to design an intervention to improve nutrition knowledge and dietary behaviour in adolescent female hockey players would be a natural next step to take this work forward.

8.4 Conclusion

The research presented in this thesis provides novel data on the anthropometric and physiological characteristics, training and match loads, energy expenditure, physical activity, dietary intake and eating behaviour in female adolescent hockey players playing at the early stages of the national talent development program. Measures of skill, speed, strength, and power were lower than found in elite (tier 4/5) adult hockey players but above population averages and similar to those found in other adolescent female athletes. The structure of adolescent hockey games, distances travelled, and phases of

play were similar to Elite U16-U18 (tier 4) and adult games, but the intensity of play was lower and there was no discernible difference between playing positions. Dietary EI was lower than recommended with most participants being in negative EB and exhibiting poor EA on training and match days. Macronutrient intake was within the recommended guidelines but was poorly distributed across the day, meaning that it was likely that neither carbohydrate or protein were optimally available to fuel the work required or promote efficient recovery. Nutrition knowledge was poor but suboptimal nutritional intake is not always deliberate and detail from the behaviour questionnaires highlighted the difficulty faced by young athletes balancing school with sports training. When taken together the results of these studies enhance our understanding of the energy requirements and sports demands of adolescent female hockey players and will assist in the formation of population specific nutrition guidelines and advice.

8.5 Practical implications

Within this thesis the adolescent female hockey players playing in the early stages of the national selection system were both fitter and more active than the general population. The amount of organised sports training varied considerably but for some individuals the number of hours reported exceeded current recommendations (Jayanthi and Dugas, 2017). The findings of Study 2 (GPS analysis of U16 League games) and the GPS component of Study 5 confirmed that the demands of hockey played at this level is similar to the adult game. The food and activity diaries completed in Study 3 and 5 showed energy intakes below both estimated and measured energy expenditure and that macronutrient intake was poorly distributed across the day. Both general nutrition knowledge (Study 5) and food selection around sports training (Study 4 and 5) and competition were poor. Energy expenditure was estimated to be XX in training and XX during competitive games.

The main recommendations for nutrition practitioners working with adolescent female hockey players would be :-

- To take all physical activity an organised training into account when discussing training commitment or training loads. Total energy expenditure may be far higher than estimated from predictive equations or using activity levels form a single sport.
- To calculate developmental age to gauge a measure of likely future growth, which needs to be acknowledged when looking at likely energy requirement. Although through age of PHV >90% of participants in studies 1 and 5 were still growing. Discussion of body composition should be avoided until individuals are close to or have exceeded predicted adult height.
- To focus on nutrition education that highlights the necessity of fuelling for the work done and matching macronutrient needs to energy expenditure over the entire day. Adequate energy and protein intake at breakfast should be encouraged.
- To include guidance on how to select and create healthy, portable meals and snacks. Greater food autonomy during adolescence coincides with the time when the most talented individuals begin to do higher volumes of training and may travel further to performance centres or games.

The main recommendation for coaches working with adolescent female hockey players would be :-

- To ensure that all sports played are taken into account giving players sufficient time to recover.

- To ensure that players take sufficient fluid and food with them when travelling to tournaments or matches and that they are aware of how to fuel for the work required.
- Focus on increasing match intensity ($m \cdot min^{-1}$) as the main difference between elite / sub-elite (level 4-5) games and the matches within Studies 2 and 5 was in this measure. Individuals were less frequently substituted and played greater pitch time but covered equivalent distance.

Appendix A

Pilot Survey

Physical Activity and Dietary Survey (Hockey) Chichester University

Page 1: Welcome

What is the study about? We are trying to find out about diet and activity in girls who do a lot of sport.

□□**Do I have to take part?**□No! It is your choice whether you take part in the survey or not. We will not be disappointed if you choose not to be involved. If at anytime during the questionnaire you feel that you don't want tocontinue then you can stop.

What will I need to do? We would like you to answer the following questions as accurately as you can. There are no right or wrong answers. The information given is anonymous and is going to be used together with some other studies to look at activity and diet in sport.

What will happen to the information I give? All data will be stored securely on a password protected computer accessible only to the researchers. We do not need your name and all data will be kept anonymously. If the research is published your information will not be recognised as an individual, the results will just show a summaryof all the people who have answered the questionnaire.

□□**Who can I contact if I have any questions about the project?** If you have any questions or concerns please contact Tilly Spurr at the University of Chichester or by email m.spurr@chi.ac.uk. This project has been approved in accordance with the University of Chichester Ethical Policy Framework.

Thank you for your time

Page 2: Data Protection Statement

I have read and understood the information provided concerning this survey.

I understand that my participation in the survey is voluntary and that I am therefore free to withdraw my involvement at any stage without giving reason.

I understand that all information will be recorded anonymously and that my personal information will not be released to third parties.

I understand that there are no right or wrong answers and that this is not a test.

I understand that if I have any questions I can contact Tilly Spurr (m.spurr@chi.ac.uk) anytime.

By clicking "continue" you are giving consent to participate in this study.

Page 3: Personal Details, Physical Activity and Dietary Survey

The survey below consists of 25 questions. Please provide an answer for them all even if this is an answer such as "I do not know" or "0", as the survey can only be submitted when an answers have been given to the questions.

If you need further information there may be a more information button on the right hand side, or you can email mspurr1@stu.chi.ac.uk

Please note that once you have clicked on the CONTINUE button your answers are submitted and you can not return to review or amend that page.

PERSONAL DETAILS

1. Date of Birth

More info

Dates need to be in the format 'DD/MM/YYYY', for example 27/03/1980.
Please make sure the date is between 01/03/1997 and 01/03/2007.

(dd/mm/yyyy)

2. Which school year are you in?

3. Which County, within the UK, do you live in?

4. How many hours of exercise did you do last week?

PHYSICAL ACTIVITY

5. How often did you do physical activity (sports, games, dance or any other type of exercise) lasting more than 20 minutes on each day of the last week?

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	Number of times						If you selected Other, please specify:
	None	1	2	3	4	Other	
Monday	○	○	○	○	○	○	
Tuesday	○	○	○	○	○	○	
Wednesday	○	○	○	○	○	○	
Thursday	○	○	○	○	○	○	
Friday	○	○	○	○	○	○	
Saturday	○	○	○	○	○	○	
Sunday	○	○	○	○	○	○	

6. Were you ill last week, or did anything else prevent you from doing your normal amount of physical activity ?

☐ Yes ☐ No

7. In the last week, what did you do most of the time at school MORNING BREAK (check only the one most relevant to you)?

- ○ Sat down (talking, reading, doing school work)
- ○ Music lesson or practice
- ○ Stood around or walked about
- ○ Played with my friends
- ○ Ran around or played sport some of the time
- ○ Played sport most of the time
- ○ Other

7.a. If you selected Other, please specify:

8. In the last week, what did you normally do at school LUNCH BREAK (besides eating lunch)?

- ○ Sat down (talking, reading, doing school work)
- ○ Music lesson or practice

- Stood around or walked about
- Played with my friends
- Ran around or played sport some of the time
- Played sport most of the time
- Other

8.a. If you selected Other, please specify:

9. In the last week, on how many days did you do a sport, gymnastics, dance or play games BEFORE school?

- None
- Once a week
- Twice or Three times a week
- Four or five times a week
- Six times a week

9.a. Do you do Saturday school

- Yes
- No

In the last week, on how many days did you do sport, dance or play organised games AFTER school

10. Before 6pm?

- None
- Once a week
- Twice or Three times a week
- Four or five times a week
- Six times a week
- Other

11. After 6pm?

- None
- Once a week
- Twice or Three times a week
- Four or five times a week
- Six times a week
- Other

10&11a. If you selected Other, please

12. On the last WEEKEND, how many times did you do sports, dance or play organised games in which you were very active?

- None
- Once
- Twice
- Three times
- Four or more times

13. Have you done any of the following activities in the past 7-days. If yes how many times?

	Number of times						
	None	1-2	3-4	5-6	7-8	Other	If you selected Other, please specify:
Aerobics							
Athletics							
Badminton							
Baseball / Softball / Rounders							
Basketball							
Bicycling							
Canoeing / Rowing							
Cricket							
Dance							
Football							
Gymnastics							
Hockey (field)							
Ice skating / Inline skating							
Jogging / Running							
Kick boxing / Martial arts							
Netball							

Riding	☐	☐	☐	☐	☐	☐	
Rugby	☐	☐	☐	☐	☐	☐	
Sailing	☐	☐	☐	☐	☐	☐	
Swimming	☐	☐	☐	☐	☐	☐	
Skiing	☐	☐	☐	☐	☐	☐	
Strength & Conditioning or weights	☐	☐	☐	☐	☐	☐	
Tennis	☐	☐	☐	☐	☐	☐	
Trampolining	☐	☐	☐	☐	☐	☐	
Ultimate Frisbee	☐	☐	☐	☐	☐	☐	
Volleyball	☐	☐	☐	☐	☐	☐	
Walking as exercise	☐	☐	☐	☐	☐	☐	
Yoga / Pilates	☐	☐	☐	☐	☐	☐	
Other (please specify)	☐	☐	☐	☐	☐	☐	

14. Is your main competitive sport hockey?

- ○ Yes
- ○ No

15. If your main sport is not hockey, what is your main competitive sport?

16. Is it your ambition to represent Great Britain

- ○ Yes
- ○ No
- ○ Maybe

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17. What level hockey team or teams have you played for this season?

- [ ] I do not play competitive hockey
- [ ] School A team
- [ ] School 1st XI
- [ ] School indoor team
- [ ] School mixed team
- [ ] Club U12
- [ ] Club U13
- [ ] Club U14
- [ ] Club U16
- [ ] Club Adult Team
- [ ] Club indoor team
- [ ] Club mixed team
- [ ] Junior Development Centre
- [ ] Junior Academy Centre
- [ ] Junior Regional Performance Centre
- [ ] Tier 1
- [ ] Tier 2
- [ ] National Age Group Squads
- [ ] Other

17a. If you selected Other, please specify:

18. Do you play county, region or national level in any other sport?

19. Where do you play hockey?

- ( ) Club
- ( ) School
- ( ) Club and School

FOOD TYPES

20. If you are thirsty between meals what do you usually drink?

- Sweetened drinks (cola, lemonade, squash, sunny delight)
- Artificially sweetened drinks (diet cola, diet lemonade, sugar free squash)
- Milky drinks (milk, milkshake, hot chocolate)
- Water (tap, bottled, still or sparkling)
- Unsweetened pure fruit juice
- Hot drinks (tea or coffee)
- Other

21. When you drink water, what type of water do you usually drink?

- I never drink plain water
- Tap water
- Filtered tap water
- Bottled still mineral water
- Bottled sparkling mineral water
- Other

22. What food and drink do you usually have before a match?

23. What food and drink do you usually have during a match or at half time?

24. What food and drink do you usually have after a match?

25. Do you take a supplement? If so what do you take?

Appendix B

Main Survey

1 / 1 100%

1. What is your date of birth

2. What school year are you in?

- ◯ Year 5
- ◯ Year 6
- ◯ Year 7
- ◯ Year 8
- ◯ Year 9
- ◯ Year 10
- ◯ Year 11
- ◯ Year 12
- ◯ Year 13
- ◯ Other (please specify)

3. Are you?

- ◯ Male
- ◯ Female
- ◯ Would rather not say

4. What county within the UK do you live in?

5. If you play competitive sport, what sports do you play and at what level?

6. What level of hockey have you played this season?

- ◯ JDC
- ◯ JAC
- ◯ PC
- ◯ NAGs
- ◯ Club adult 1st team
- ◯ Club adults team (other than 1sts)
- ◯ Club U16
- ◯ Club U14
- ◯ Club U12
- ◯ School 1st team
- ◯ School U15/U16
- ◯ School U13/U14
- ◯ School U12

Other (please specify)

7. What other sports do you play competitively and at what level?

8. Were you ill last week? Or was there anything that made this week unusual or different from a normal week?

- ◯ Yes
- ◯ No

9. Do you have Saturday school?

- ◯ Yes
- ◯ No

10. How many times in the last week did you do sport, games, dance or any other physical activity lasting over 20 minutes?

	None	Once	Twice	Three times	Four times	More
Monday	◯	◯	◯	◯	◯	◯
Tuesday	◯	◯	◯	◯	◯	◯
Wednesday	◯	◯	◯	◯	◯	◯
Thursday	◯	◯	◯	◯	◯	◯
Friday	◯	◯	◯	◯	◯	◯
Saturday	◯	◯	◯	◯	◯	◯
Sunday	◯	◯	◯	◯	◯	◯

Other (please specify)

11. How much time (to the nearest hour) did you spend playing sport last week?

12. In the last week, what did you do most of the time at school MORNING BREAK?

- ◯ Sat down talking, reading or doing school work
- ◯ Music lesson or practise
- ◯ Stood around or walked around
- ◯ Other (please specify)
- ◯ Played with my friends
- ◯ Ran around or played sport some of the time
- ◯ Ran around or played sport all of the time

13. In the last week what did you normally do at school LUNCH BREAK?

- ◯ Sat down talking, reading or doing school work
- ◯ Music lesson or practise
- ◯ Stood around or walked around
- ◯ Other (please specify)
- ◯ Played with my friends
- ◯ Ran around or played sport some of the time
- ◯ Ran around or played sport all of the time

14. In the last week how many days did you do a sport, gymnastics, dance or play games BEFORE school?

- ◯ 0
- ◯ 0ne
- ◯ Two
- ◯ Three
- ◯ Four
- ◯ Five
- ◯ Six

15. In the last week how many days did you do sport, dance, gymnastics or play games AFTER school?

- ◯ 0
- ◯ One
- ◯ Two
- ◯ Three
- ◯ Four
- ◯ Five
- ◯ Six

16. At the WEEKEND how many times do you usually do sport, gymnastics dance or play organised games lasting over 20minutes?

- ◯ None
- ◯ One
- ◯ Two
- ◯ Three
- ◯ Four

Other (please specify)

17. In the last week how many days did you eat breakfast?

- ◯ I always eat breakfast
- ◯ I rarely or never eat breakfast
- ◯ Once or twice
- ◯ Three or four days
- ◯ Five or more days
- ◯ Always

18. In the last week how many times did you eat breakfast at home?

- ◯ Rarely/never
- ◯ 1-2
- ◯ 3-4
- ◯ 5 or more
- ◯ Always

19. If not eaten at home, where do you eat breakfast?

- ◯ In the car
- ◯ On the bus or train
- ◯ Other (please specify)
- ◯ At school
- ◯ At a sports club

20. Given the choice, on days where you do not have to be anywhere, at what time are you most likely to eat breakfast?

Appendix B

21. LUNCH. In the last week how often did you eat?.....

	Never	0-1	2-3	4-5	6-7
A cooked lunch in the school dining room	○	○	○	○	○
A packed lunch bought from home	○	○	○	○	○
A packed lunch provided by school	○	○	○	○	○
Bought something for lunch from the school canteen, tuck shop or vending machine	○	○	○	○	○
Went out of school to buy something for lunch	○	○	○	○	○
Miss lunch as I was playing sport or in a club/revision	○	○	○	○	○
Skip lunch	○	○	○	○	○

22. SUPPER. In the last week how many times did you eat your evening meal?.....

	Never	0-1	2-3	4-5	6-7
A meal that was prepared, cooked and eaten at home.	○	○	○	○	○
A meal that was eaten at a restaurant, fast food restaurant or cafe	○	○	○	○	○

A take away meal, eaten at home	○	○	○	○	○
A meal at home that was ready made and just reheated	○	○	○	○	○
Your evening meal in a car, train or bus	○	○	○	○	○
Your evening meal at school	○	○	○	○	○
Your evening meal at a sports venue	○	○	○	○	○
Your evening meal at school	○	○	○	○	○
Your evening meal at a sports venue	○	○	○	○	○
Skip an evening meal	○	○	○	○	○

Other (please specify)

23. Are there any foods that you always avoid eating? (You can give more than one answer)

- [ ] Meat
- [ ] Fish
- [ ] Cows milk
- [ ] All dairy products
- [ ] Egg
- [ ] Gluten
- [ ] Other (please specify)
- [ ] Nuts
- [ ] Green vegetables
- [ ] High fat foods
- [ ] Sugar
- [ ] Artificial sweeteners

24. Why do you avoid these foods?

25. If you are thirsty between meals what do you usually drink?

- ◯ Sweetened drinks (cola, lemonade, squash, sunny delight)
- ◯ Artificially sweetened drinks (diet cola, diet lemonade, sugar free squash)
- ◯ Milky drinks (milk, milkshake, hot chocolate)
- ◯ Other (please specify)
- ◯ Water (tap, bottled, still or sparkling)
- ◯ Unsweetened pure fruit juice
- ◯ Hot drinks (tea or coffee)

26. When you drink water, what type of water do you drink?

- ◯ I never drink water
- ◯ Tap water
- ◯ Filtered tap water
- ◯ Other (please specify)
- ◯ Bottled still mineral water
- ◯ Bottled sparkling mineral water

27. When you play sport, what drinks do you have before, during or after a match? (You can choose more than one)

	Before a match	During a match	After a match
I do not drink	◯	◯	◯
Water	◯	◯	◯
Ready made commercial sports drinks (Lucozade sport, Powerade, Gatorade)	◯	◯	◯
A homemade sports drink or juice	◯	◯	◯
Coconut water	◯	◯	◯
Coffee, tea or other caffeinated drink	◯	◯	◯

A homemade sports drink or juice	○	○	○
Coconut water	○	○	○
Coffee, tea or other caffeinated drink	○	○	○
Milk or milk based drink	○	○	○
Ready made commercial recovery drink	○	○	○
Home made recovery drink	○	○	○
Energy drink (Red bull, Lucozade, Monster or caffeinated sports drink)	○	○	○
Smoothie	○	○	○

Other (please specify)

28. When you play sport, what types of foods do you eat before, during or after a match? (You can choose more than one)

	Before a match	During a match	After a match
Pasta or noodles	◯	◯	◯
Jacket potato	◯	◯	◯
Banana	◯	◯	◯
Orange	◯	◯	◯
Apple or other fresh fruit	◯	◯	◯
Dried fruit	◯	◯	◯
Sports bar, sports gel, sports sweets	◯	◯	◯
Jelly babies, jelly beans, jelly sweets	◯	◯	◯
Fig rolls, malt loaf or similar	◯	◯	◯
Cereal bar	◯	◯	◯
Bread and jam	◯	◯	◯
Match tea provided.	◯	◯	◯
Match tea provided.	◯	◯	◯
Crisps	◯	◯	◯
Cheese	◯	◯	◯
Nuts	◯	◯	◯

Other (please specify)

29. Do you take a mineral or vitamin supplement? If yes what do you take?

30. Do you take a sport supplement? If yes, what supplement do you take?

31. What type of milk or milk alternative do you usually drink or use on cereal?

- ◯ I do not drink or use milk
- ◯ Whole fat (blue) milk
- ◯ Semi skimmed (green) milk
- ◯ Skimmed (red) milk
- ◯ Non-cow dairy milk (goat, sheep)
- ◯ Nut milk
- ◯ Soy milk
- ◯ Oat milk
- ◯ Pea milk
- ◯ I am not sure

Other (please specify)

32. What type of bread do you usually eat?

- ◯ I do no eat bread
- ◯ White
- ◯ Half and half or fortified white
- ◯ Brown, wholewheat or granary
- ◯ Other (please specify)
- ◯ Flatbread, pitta, bagels, wraps
- ◯ Gluten free bread
- ◯ I am not sure

33. What type of butter or spread do you usually eat?

- ◯ I don't eat butter or spread
- ◯ Butter
- ◯ Spreadable butter
- ◯ Margarine (such as flora, clover, stork, I can't believe it is not butter)
- ◯ Olive oil spreads (Bertolli, Olivio, Benecol, Biona)
- ◯ I am not sure
- ◯ Other (please specify)

34. Is there usually fruit freely available to eat at home?

- ◯ Yes
- ◯ No

35. Is there usually fruit freely available to eat at school?

- ◯ Yes
- ◯ No

36. How many servings of fruit and vegetables a day do experts advice people to eat?

- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5 or more
- ◯ Not sure

37. Do you think these foods and drinks are typically high or low in added sugar?

	High Sugar	Low Sugar
Diet cola drinks	◯	◯
Natural yoghurt	◯	◯
Ice cream	◯	◯
Tomato ketchup	◯	◯
Melon	◯	◯
Breakfast Cereals	◯	◯

38. Do you think these foods and drinks are typically high or low in salt?

	High Salt	Low Salt
Breakfast cereals	◯	◯
Frozen Vegetables	◯	◯
Bread	◯	◯
Baked Beans	◯	◯
Red meat	◯	◯
Canned soup	◯	◯

39. Do you think these foods and drinks are typically high or low in fibre?

	High Fibre	Low Fibre
Oats	◯	◯
Banana	◯	◯
White Rice	◯	◯
Eggs	◯	◯
Potato with skin	◯	◯
Pasta	◯	◯

40. Do you think these foods are a good source of protein?

	High Protein	Low Protein
Poultry	◯	◯
Cheese	◯	◯
Fruit	◯	◯
Baked Beans	◯	◯
Butter	◯	◯
Nuts	◯	◯

41. Do you think these foods are high or low in fat?

	High Fat	Low Fat
Milk	◯	◯
Chocolate biscuits	◯	◯
Egg	◯	◯
Tuna	◯	◯
Avocado	◯	◯
Bread	◯	◯

42. The amount of calcium intake a glass of whole milk compared to a glass of skimmed milk is (tick one)

- ◯ About the same
- ◯ Much higher
- ◯ Much lower
- ◯ Not sure

43. Which of the following nutrients has the most energy (calories) for the same weight of food?

- ◯ Sugar
- ◯ Starchy carbohydrates (eg potato)
- ◯ Fibre / roughage (eg bran)
- ◯ Fat
- ◯ Not sure

44. Compared to foods that have not been processed, a processed food is usually? (Tick one)

- ☐ Higher in calories
- ☐ Higher in fibre
- ☐ Lower in salt
- ☐ Not sure

45. Do health professionals or nutritionists recommend that you eat more, the same amount, or less of the following foods?

	More	Same	Less	Not sure
Fruit	◯	◯	◯	◯
Food and drinks with added sugar	◯	◯	◯	◯
Fatty foods	◯	◯	◯	◯
Processed red meat	◯	◯	◯	◯
Wholegrains	◯	◯	◯	◯
Salty foods	◯	◯	◯	◯
Water	◯	◯	◯	◯

Done 😊

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