An observational study on the dietary intake, nutrition practices, hydration status and energy expenditure in competitive one-day cricket matches

A thesis presented in partial fulfillment of a Masters of Science in Human Nutrition

Massey University, Albany, New Zealand

Shelley McDonald

2018

Abstract.

Background: Cricket is one of the oldest sports in existence, the first international match dates back to 1844. Modern day cricket with increasing elite level representation has resulted in higher physical performance demands on players. Despite this there is little information available regarding the energy cost, dietary intake and hydration status of cricket players during matches.

Objective: To investigate pre-match and match dietary intake, hydration status and energy expenditure (EE) of competitive male players within 50-over cricket matches.

Methods: Competitive male cricket players (>16y) from the Auckland Cricket Association were invited to participate in an observational study that took place during competitive 'one-day format' cricket matches. Early morning pre-match hydration was tested for urine specific gravity (U_{sg}), end of match hydration was determined from percentage body mass (BM) change and sweat loss was estimated from end of match BM less calculated BM (pre-match BM + food and fluid mass – urine output). Dietary intakes were assessed using food records (pre-match) and direct observation (during match). Global positioning system units were worn to provide time motion analysis data. EE was calculated from relative metabolic load multiplied by pre-match BM. Statistical analyses using independent t-tests and bivariate correlations were performed to investigate relationships between variables.

Results: Match data were collected from 27 cases over six games from 18 participants. Early morning pre-match dehydration ($\geq U_{sg}$ 1.020 $g{\cdot}ml^{-1}$) was reported in 81.5% of cases. The minimum recommended pre-event fluid intake (5 $ml{\cdot}kg^{-1}$) was met by 28% of participants (n=5). A pre-match carbohydrate (CHO) intake of <1 $g{\cdot}kg^{-1}$ was reported for 66.6% of participants, and match CHO intake of < 30 $g{\cdot}h^{-1}$ was found for 37% of cases. End of match BM percent losses occurred in 59.2% and the highest loss reported was 2% (n=2). Match fluid intake was positively associated with match sweat loss (P<0.001). The average match EE per hour was 1015 ± 266 $kJ \cdot h^{-1}$. There was no relationship between match EE and energy intake.

Conclusion: Most players were dehydrated early morning, and almost one third had an inadequate pre-match fluid intake. Match rehydration was insufficient in over two-thirds of the cases and CHO intake was insufficient for two thirds pre-match and for one third during the match. The results from this study indicate that educating this group of cricket players on pre-match and match dietary and fluid requirements and on individual hydration monitoring practices is warranted. Further investigations on the energy cost of cricket matches are warranted to further determine the demands of the game, specifically focusing on positional demands.

Acknowledgements.

A number of people generously gave up their time to contribute to this study.

I would like to express my gratitude to my academic supervisors, Dr Kathryn Beck, Associate Professor Pamela von Hurst and Associate Professor Andrew Foskett, your individual expertise, guidance and support was invaluable. To my lead supervisor Dr Kathryn Beck, you were instrumental to the completion of this study and I thank you for your ongoing words of encouragement.

Special thanks also to Massey University research and support staff, Owen Mugridge, PC Tong, and Kate McMaster, you assisted with data collection and shared with me your vast knowledge and skills.

To Daniel Gordon for your expertise and time, specifically in the application of GPS and to my fellow student Corey Payne for being by my side supporting and contributing to this study throughout the journey.

Further thanks also to Julie Heaton your supervisory role in the practical and technical aspect of the dual energy x-ray absorptiometry analysis, and to Adriana Hepburn for research assisting with me the final game.

Finally I would like to thank Paul McKinnon (former ACA High Performance Manager), Nick White (Current Performance and Pathways Manager), Scott McLaren, (former ACH Strength and Conditioning Specialist) and Andre Adams, (Auckland A Team Head Coach) from the Auckland Cricket Association, for their co-operation and support with recruitment and data collection.

And last but not least my thanks goes to the participants themselves, without whom this study could not have taken place.

Table of Contents

List of Tables.

List of figures.

Abbreviations.

ACA Auckland Cricket Association

BIA Bioelectrical impedance analysis

BM Body mass

BM% Body mass percent

BMI Body mass index

CHO Carbohydrate

DC Direct calorimetry

DLW Doubly labeled water

DXA Dual energy x-ray absorptiometry

EE Energy expenditure

ESL Estimated sweat loss

GPS Global positioning system

HR Heart rate

IC Indirect calorimetry

SEE Standard errors of estimate

TMA Time motion analysis

1. Introduction.

1.1. Background.

The game of cricket boasts a long-playing history dating back to the 16th century with the first recorded match being almost 300 years ago (Noorbhai and Noakes, 2015, Fourny *et al.*, 2005). The physiological demands and nutritional requirements of cricket are dependent on a number of aspects including the format of the game itself. Cricket is played in three different formats: Test cricket: a multiday day game completed in no more than 5 days, it includes four innings and lasts approximately 6 hours per day. The "limited overs" games include: One-day, permitting up to 50 overs per innings lasting ≥6 hours in total and Twenty-20, allowing a maximum of 20 overs per innings, typically completed within 3 hours. Within each of these formats, periods of play can include spells of intense or limited energy expenditure (Duffield and Drinkwater, 2008, Rudkin and O'Donoghue, 2008). Movement patterns differ considerably between game formats and player positions (Petersen *et al.*, 2010). Observation of games in one-day cricket would suggest that a bowler may bowl up to 60 balls per innings or none at all, and a fielder may spend up to 3 hours on the field, mostly standing with infrequent but short intense bursts of running. In the batting innings, a batter may be in bat and intermittently sprinting between wickets for as long as two hours, where as another may remain seated in the pavilion for the entire innings.

Research on cricket and players is limited compared to other team sports, with much of the focus on injuries (Finch *et al.*, 2010, Frost and Chalmers, 2014, Orchard *et al.*, 2015), technique (Ferdinands *et al.*, 2010), biomechanical analysis (Burnett *et al.*, 1995, Penn and Spratford, 2012, Portus *et al.*, 2000, Stronach *et al.*, 2014a, Stronach *et al.*, 2014b) and some on anthropometric assessment (Stretch, 1987, Stuelcken *et al.*, 2007, Koley, 2011, Micklesfield *et al.*, 2012, Johnstone *et al.*, 2014, Lees *et al.*, 2016).

An increase in team representation at professional and international levels across the various playing formats over longer playing seasons is increasing the competitiveness and performance demands on players (Noakes and Durandt, 2000). The 2013/2014 Active New Zealand (NZ) survey results indicated that 5.7% of New Zealanders and 8.7% of NZ males participated in cricket. Within NZ Asian ethnicities cricket participation ranked 6th within the 10 most popular sport category, with a reported 12.4% participation, and ranked first for team sports (Haughey, 2015).

Preparing elite cricketers to perform consistently at high levels is challenging when aspects of the game, such as duration and intensity are less predictable than other field sports. For example in football, playing duration is pre-determined by the laws of the game, and the intensity and energy expenditure (EE) within the playing positions is more predictable due to the set nature of playing time. The scientific literature describes cricket as a sport involving long periods of low intensity and limited EE, in fielding (Rudkin and O'Donoghue, 2008) and batting (Duffield and Drinkwater, 2008), with intermittent bouts of high intensity movement in fielding (MacDonald *et al.*, 2013a), batting and bowling (Petersen *et al.*, 2010).

Within the scant literature there exists some belief that cricket is less demanding a game compared to other team sports (Duffield and Drinkwater, 2008, Fletcher, 1955, Rudkin and O'Donoghue, 2008), yet anecdotally it is well known that players experience high levels of physical and cognitive fatigue (Bartlett, 2003, Duffield and Drinkwater, 2008, Noakes and Durandt, 2000). Coaches and players are interested to know why and yet, there have been no reliable explanations for this phenomenon to date other than the view that multiple factors must contribute. Cricketing skills across playing positions require substantial mental effort and concentration (Jooste *et al.*, 2013). It is a known fact that dietary intake and hydration status impact on performance in other sports (Thomas *et al.*, 2016), yet no studies to date have reported on the dietary intake and nutritional status in cricket players or observed nutritional practices around training or games.

The earliest study investigating EE of cricketers was completed in 1955. Fletcher et al (1955) concluded from this single study, the mean EE for a cricketer during a test match was as low as that of walking. It appears that this view may have been either accepted or simply not come into further question until recently. Most attempts to describe the demands on cricketers have been derived from studies observing heart rate monitoring, intensity and movement patterns. Only two further investigations on EE in cricket have occurred since 1955. These were conducted in simulated experimental conditions investigating the EE of batting via gas exchange methodology and calculated higher EE than the earlier works of Fletcher (Christie *et al.*, 2008, Pote and Christie, 2014).

Only a handful of investigations on the effects of hydration in cricketers can be found. Experimental design cross-over studies that have investigated the effects of dehydration in cricketers on performance have shown dehydration to 2.8% body mass (BM) loss impairs bowling accuracy (Devlin, 2001) and that further impairments in bowling accuracy and in other cricket specific skills occur at a loss of 3.7% (Gamage, 2016). A study that was famous for highlighting the need for increased player drinking opportunities during cricket matches, reported inadequate fluid intake and BM loss as high as 4.3% in cricket players in hot conditions (Gore, 1993). Dehydration, although to a lesser extent, has also been reported in high performance female cricket players (Soo, 2007).

1.2. Purpose of the study.

With increasing competitive elite levels of play, further information regarding the physiological, nutritional and energy demands would be useful to help inform coaches and athletes in areas relating to maintaining optimal health and cricket sporting performance. Literature regarding physiological factors affecting cricket performance is sparse and fluid intake has been the only nutritional factor researched in cricket. The nutritional status of cricket players is largely unknown, and there are no published reports regarding dietary practices before, during and post games. With such little background information to go by, it is difficult to make accurate statements with regards to nutritional requirements specifically related to cricket. Investigation into cricket players dietary intake, hydration practices, hydration status, and EE during games would contribute to a new body of knowledge in this area. It is hoped the findings of this study will begin to shed some light on the topics relating to the dietary intake, energy cost and hydration of one-day cricket players during games and provide a starting point towards defining and establishing future dietary guidelines for this sport.

1.3. Aim.

The aim of this study is to investigate the dietary intake, nutrition practices, hydration and energy expenditure of competitive cricket players during one-day fixtures.

1.3.1. Objectives.

1. To estimate the dietary and fluid intake and describe the nutrition practices of cricket players before and during one-day cricket games.
2. To assess hydration status of cricket players before and at the end of one-day cricket games.
3. To determine the energy expenditure of cricket players during one-day cricket games.
4. To determine the percentage of cricket players that adhere to and meet team sport nutrition and fluid guideline recommendations
5. To examine associations between fluid intake, energy intake, energy expenditure, hydration, estimated sweat loss and environmental temperature conditions at one-day cricket games.

1.4. Thesis Structure.

The body of the thesis contains five chapters. The first chapter provides an introduction to the game of cricket and a brief background into the existing published cricket related scientific literature. A rationale for the need to begin to gather information on areas where the gaps exist (relating to nutrition, hydration and energy cost during matches) is presented preceding a description of the aim and objectives of the study. The literature review (chapter two) covers dietary, anthropometric, hydration, EE assessment, and summarises relevant information known on these topics relating to cricket. The third chapter describes methodologies used across the three phases of the study, and the fourth chapter outlines the results. As a result of the new body of knowledge from the current study, the final chapter (chapter five) acknowledges the strengths and limitations of the study and draws on conclusions and provides recommendations and suggestions for further study

1.5. Researchers' Contributions.

Table 1.1: Researchers contributions to this study

Author	Masters thesis contributions
Shelley McDonald	• Lead researcher • Study design & ethics application • Participant recruitment • Project management • DXA measurements (densitometry) • Data sorting, analysis & statistical analysis • Data interpretation • Primary author
Dr Kathryn Beck	• Lead professional supervisor • Study design & ethics application • Lead thesis reviewer • Research assistant: phase 2 & 3
Dr Pamela von-Hurst	• Professional supervisor • Study design & ethics application • Thesis review
Dr Andrew Foskett	• Professional supervisor • Phase 3 study design support • Thesis review
Owen Mudridge	• Research assistant: phase 2 & 3 • Dual-energy x-ray absorptiometry (DXA) measures • Data coding support
P.C Tong	• DXA data analysis and support
Daniel Gordon	• Research assistant: phase 3 • Lead global positioning system support person
Kate McMaster	• Research assistant: phase 3 • GPS and refractometer support
Corey Payne	• Research assistant: phase 2 & 3 • Updated study participant demographic, lifestyle and health questionnaire
Julie Knight	• Phase 2: DXA support and supervision
Adriana Hepburn	• Research assistant: phase 3

2.0. Literature Review.

2.1. Overview.

An objective critical summary of the published research literature, including review papers and position statements from scientific journals are described. The literature review includes an overview of the current dietary and hydration recommendations for athletes and an outline of diet, hydration and anthropometric assessment methodologies. Subsequently, existing studies on the dietary intake, hydration, and anthropometry of cricket players are then summarised. A synopsis of energy expenditure analysis methodologies precedes an examination of the literature's account on the physiological requirements of cricket, with a specific focus on exercise intensity, and energy cost.

2.2. Sports nutrition goals and guidelines.

Nutritional needs for athletes differ to that of non-athletes. In addition to fulfilling dietary daily requirements to maintain health, bodily functions and growth (in young athletes), diets must also support the demands of training, competition, recovery and in some cases target prerequisite sporting related body composition goals (Thomas *et al.*, 2016). The goals of nutrition are often different around training and competition. For example, during sporting events, plans that support acute fuel demands and cognitive function are paramount (Thomas *et al.*, 2016). Evidenced-based sports nutrition guidelines have been developed based on the science behind delivering the most suitable substrate or substrate combinations to best fuel the human energy system or systems being utilised. Therefore an athlete's nutritional needs are somewhat determined by the demands of the sport and playing positions. High performance and competitive athletes undergo periodised training schedules, have rigorous event calendars and short recovery times between activities, thus their daily energy, nutrient and fluid needs are not static (Thomas *et al.*, 2016). Modifying daily dietary intake is necessary to address the specific nutrient needs of each day in accordance to the characteristics of the activity. Evidence-based sport nutrition guidelines acknowledge this and recommend that daily energy and macronutrient (carbohydrate and protein) goals are calculated relative to body mass (Thomas *et al.*, 2016). The importance of critical timing of nutrient supply is also described for carbohydrate and protein. Timing of carbohydrate supply has been shown to be important for energy availability and prevention of fatigue (Thomas *et al.*, 2016, Williams and Rollo, 2015) and the apt timing of protein ingestion has been found to enhance metabolic adaptation via the maintenance or increase in muscle protein turnover and support of muscle repair during recovery (Phillips and Van Loon, 2011).

National sporting authorities often provide nutritional fact sheets that can be accessed from their website. For example, the Australian Institute of Sport has previously developed nutrition facts sheets for cricket (Australian Institute of Sport, 2016), and Sports Dietitians Australia have provided practical advice in the development of a cricket fact sheet (Sports Dietitians Australia, 2016). Dietary recommendations in the sport of cricket have likely been extrapolated from research conducted in endurance and other team sports, from peer-reviewed position stands, (Thomas *et al.*, 2016), consensus statements (International Olympic Committee, 2011), and from other key expert published reviews (Williams and Rollo, 2015, Burke *et al.*, 2011, Phillips *et al.*, 2011). Guidelines are generic, and it is recommended that assessment and guidance for translating energy and nutrient recommendations into practice for individual athletes is conducted and communicated by knowledgeable experienced sports nutrition experts (International Olympic Committee, 2011).

2.2.1. Sports nutrition guidelines for carbohydrate.

Half a century ago the link between dietary carbohydrate (CHO), muscle glycogen and prolonged intense activity was determined (Bergström *et al.*, 1967). Carbohydrate continues to be recognised as the key nutrient that maintains glycogen stores and blood glucose levels over prolonged and intermittent high-intensity exercise (Thomas *et al.*, 2016). Declining energy stores are associated with fatigue, impaired skills and concentration (Thomas *et al.*, 2016). Effective key nutrition strategies around carbohydrate intake in sports have been developed to support glycogen muscle storage adequacy before, during, and after activity. Specific recommendations around when to consume high versus low glycemic index carbohydrate foods or drinks have also been suggested (Williams and Rollo, 2015). A compilation of current evidence-based guidelines for carbohydrate intake for day-to-day nutrition, pre-competition and during competition (Thomas *et al.*, 2016, Burke *et al.*, 2011) is provided in Table 2.1.

2.2.2. Sports nutrition guidelines for protein.

Guidelines on the amount, timing and quality of protein have mostly been developed from investigations on the promotion and up-regulation of muscle protein synthesis (Thomas *et al.*, 2016) within resistance training based sessions (Tipton, 2011, Moore *et al.*, 2009). Animal based proteins (meat and dairy) are high quality proteins providing all the essential amino acids (Jäger *et al.*, 2017). A higher intake of protein (1.2 – 2.0 $g{\cdot}kg^{-1}{\cdot}d^{-1}$) than that which is recommended in national public guidelines has been recommended for athletes (International Olympic Committee, 2011, Phillips and Van Loon, 2011). More recently, recommendations suggesting a higher lower end intake (1.4 – 2 $g{\cdot}kg^{-1}{\cdot}d^{-1}$) have been cited (Jäger *et al.*, 2017). Recommendations are set at the upper range for hypertrophy and/or strength goals (Tipton, 2011). A further recommendation has suggested that protein consumption nearer the upper range may benefit injured athletes during forced extended rest-recovery periods (Thomas *et al.*, 2016).

2.2.3. Sports nutrition guidelines for fat.

Fat oxidation plays an important role in supplying energy to the muscle during non-sprint periods of a game, and is utilised as an effective fuel substrate in well trained continuous endurance athletes (Thomas *et al.*, 2016). Athletes are recommended to consume fat as part of their daily diet in amounts set out by national public health dietary guidelines (Thomas *et al.*, 2016), and in some circumstances to consume slightly more for energy balance and to promote adequate consumption of essential fatty acids (Kreider *et al.*, 2010). An intake below 20% is generally not recommended, but may be warranted and prescribed over short time periods in exceptional circumstances (Thomas *et al.*, 2016). A fat intake of less than 20% from total energy has been reported to have negative effects on physical health and sporting performance (Thomas *et al.*, 2016). High fat meals or snacks can slow down carbohydrate availability (Williams and Rollo, 2015), and limiting the amount of fat consumed before and during physical activity is usually recommended (Thomas *et al.*, 2016).

Table 2.1: Carbohydrate guidelines in sports nutrition.

	Daily recommendations				**During activity recommendations**			**Pre–event**	**Post-event**	
Activity Type.	LIGHT Low intensity or skills based.	MODERATE ~1 $h \cdot day^{-1}$.	HIGH Endurance Mod-high intensity 1-3 $h \cdot day^{-1}$.	VERY HIGH Mod- high intensity >4-5 $h \cdot day^{-1}$	Sustained high intensity 45-75 min.	Stop/start sports 1-2.5 h.	Endurance >2-3 h.	>60 min Ex.	Immediate recovery following Ex of up to 4 h.	Daily recovery following Ex of moderate-duration/low intensity.
CHO amount.	**3-5 $g \cdot kg^{-1} \cdot day^{-1}$.**	**5-7 $g \cdot kg^{-1} \cdot day^{-1}$.**	**6-10 $g \cdot kg^{-1} \cdot day^{-1}$.**	**8-12 $g \cdot kg^{-1} \cdot day^{-1}$.**	**Small amounts & mouth rinse.**	**30-60 $g \cdot h^{-1}$.**	**Up to 90 $g \cdot h^{-1}$.**	**1-4 $g \cdot kg^{-1}$ 1-4 h pre-game.**	**1.0 – 1.2 $g \cdot kg^{-1} \cdot h^{-1}$.**	**5 – 7 $g \cdot kg^{-1} \cdot day^{-1}$**
What & how to consume.	Spread out consumption over duration of the day.				'Top ups' to refuel when necessary & practical.	Gels (if practiced) or sports drinks or easy digestible CHO rich sources.		Easy digest CHO-rich sources low-moderate in fibre & fat	Moderate-high GI foods / liquids in frequent intervals & within 1st h if in Glyc depletion	Moderate-high GI foods / liquids Nutrient rich CHO foods & can consume as series of snacks.
Rationale & Benefits.	Promotes high CHO availability. Is utilised by the anaerobic and aerobic pathways to provide ATP in the muscle.				Carbohydrate rinsing: enhances *skills acquisition* reduces possible *gastro intestinal discomfort.*	Fast delivery of glucose to muscle.		Increase CHO storage pre event helps delay onset of *fatigue* Low fat/fibre enhance glucose uptake & CHO availability.	Highest rate of MGlyc storage & synthesis in the 1st h post exercise.	For optimal restoration of MGlyc between workouts. Nutrient rich; assists in recovery processes.

CHO = carbohydrate, **Ex** = exercise, **h** = hour/s, **GI** = glycemic index**, Glyc –** glycogen**, min** = minutes, **MGlyc** = muscle glycogen

The guidelines on this table have been collated and replicated from: the 2016 ACSM Position statement "Nutrition and Athletic Performance" (Thomas *et al.*, 2016), Carbohydrate, Nutrition and Team Sport Performance, (Williams and Rollo, 2015), The Governor has a weet tooth – Mouth sensing of nutrients to enhance sports performance, (Burke and Maughan, 2015), Carbohydrate Ingestion during Team Games Exercise (Phillips *et al.*, 2011), Carbohydrates for training and competition (Burke *et al.*, 2011), Carbohydrates for training and recovery (Burke *et al.*, 2004)

2.3. Athlete dietary assessment.

In the athletic population, health and sporting performance can be related back to nutrient intake. Dietary assessment measures energy and nutrient intake and can help identify athletes that require nutrition monitoring and support (Deakin *et al.*, 2015). Specific training diet plans are designed to promote wellness and incorporate nutrition strategies that support training, optimal performance and recovery (Thomas *et al.*, 2016). For those involved in the health and training of individual athletes or athletic groups, the completion of comprehensive nutritional status assessment/s not only enables the detection of nutritional risk or related problems that might exist, but also helps inform the planning of nutrition programmes that facilitate participation longevity and optimise sporting performance goals (Thomas *et al.*, 2016). In its entirety a completed nutritional status assessment includes clinical, biochemical and anthropometric assessment. The methods chosen depend on the tools available, the skill of the people collecting the data and on whether the assessment is for individual health and performance monitoring, or for a group of athletes in a research setting (Deakin *et al.*, 2015). This literature review section focuses primarily on diet assessment.

2.3.1. Dietary Assessment Methodology.

Methods of dietary assessment are completed retrospectively via food frequency questionnaires (FFQ), diet history and 24-hour food recall, or prospectively via food records or direct observation. The weighed record is accepted in the field as the gold standard dietary assessment method, and is used to validate other dietary assessment methods. Within the field it is also known though that no dietary assessment method is without limitations (Cade *et al.*, 2002). The various sources of error in dietary assessment methods are generally understood and recognised by nutrition researchers and practitioners. Strengths and limitations of dietary assessment methodologies are well documented elsewhere (Deakin *et al.*, 2015).

2.3.2. Prospective methodology.

Food records are recorded in a food diary at the time of consumption and deemed to be the most accurate dietary assessment method in the research setting. They are either are weighed or estimated, self reported or observed. A limitation of prospective methodologies includes the potential change to an individuals usual dietary food choice and intake (Deakin, 2010, Stockley, 1985, Deakin *et al.*, 2015). Food records capture current intake over short specific time periods or assess long-term habitual dietary intake via repeated recordings of intake (eg. multiple daily food records repeated a few months apart). The food diary describes the type of food and drinks consumed, includes brand names where applicable, specifies the quantity (amount eaten), and describes when (time) and sometimes, where (location) the food and drink was consumed.

In estimated food records, amounts are recorded in grams (g) or mililitres (ml) from pre-packaged and labeled foods and drinks, from size and portion descriptions, e.g. 1 slice of white toast bread, from household measure estimates (cups and spoons), or from food model or picture estimates. In weighed food records, all foods, including plate wastage is weighed and recorded in the food diary. Analysis for both methods is calculated from entering diet records into relevant up to date national food composition databases.

The method chosen (estimated or weighed) and number of food records required (singular of duplicate) depends on the goals of the dietary assessment and the level of precision required. Food records are versatile enough to allow for multiple types of nutritional needs assessments. For example, they have been used to describe athletes' long-term dietary habits (Aerenhouts, 2011), to report on an athletic group's nutritional status (Beck, 2015) and to investigate nutrition intake over specific set time periods; for example to assess an athlete group's nutritional recovery practices (Pettersson, 2014).

2.3.3. Retrospective methodology.

Food recall methods such as the 24-hour food recall, FFQ and diet-history, are also used in research, and often in larger scale epidemiological population studies where the food or nutrient intake of a large group or cohort is sought.

Repeated at random 24-hour recalls involve the use of nutritionally trained experienced personnel for the interviewing subjects on their previous days dietary intake. The 24-hour recall approach is often used in national level population nutrition surveys (Parnell *et al.*, 2011). The FFQ is a food-list questionnaire designed to obtain information on the quantity of food that is typically eaten within a specific time period (Cade *et al.*, 2002). The respondent chooses the answer that best fits their usual eating behaviour. The FFQ is used to assess intake from "specified" foods, food groups or nutrients over a defined time period; 24 hours to one year, and does not necessarily assess an entire diet (Cade *et al.*, 2002). FFQs can rank intake and have been used as screening tools in the athlete population (Braakhuis, 2011; Heaney, 2010; Nikić, 2014).

A complete diet-history is used to verify usual eating patterns. It is a detailed assessment method and comprehensive enough to provide findings that capture seasonal differences in eating. The completion of the 24-hour diet recall and FFQ are required to fulfill this assessment method, the inclusion of a multiple day food diary can also be incorporated.

2.4. Dietary intake of cricketers.

To date, to the best of the author's knowledge, no published data exists on the usual dietary intake of cricketer players. The nutrition practices and energy intake of cricketers around training and match times are also largely unknown, making the development of evidenced-based nutrition guidelines for cricket challenging.

2.5. Dehydration in athletes: etiology and risk.

It has long been known that commencing physical activity in a dehydrated state can put the body under excess physiological stress and reduce performance

(Maughan, 2008). Various factors impact on the hydration levels of athletes. These include changeable intermittent unpredictable work rates (Burke, 1997, Burke and Hawley, 1997), hot environmental conditions, the clothing worn, (Sawka *et al.*, 2007), limited access to fluid during games (Burke, 1997, Burke and Hawley, 1997) and individual variations in sweat loss (Baker, 2017). Euhydration is the term used to describe being in total body water balance. Euhydration is not a steady state (Shirreffs, 2003) and can be even more pronounced in athletes. In the athlete population euhydration has been defined as maintaining a body weight within 0.45 kg across days (Oppliger and Bartok, 2002).

Within the sporting literature dehydration has been described as "failure to drink enough fluid to replace sweat losses during a game" and "dehydration may be exacerbated if player begins match in fluid deficit" (Mujika and Burke, 2011). While individual differences in dehydration tolerance levels exist and loss of BM in higher temperatures exacerbate the effects (Sawka *et al.*, 2007), experts agree that athletes should aim for not more than 2% BM loss. Body mass losses >2% can increase cardiovascular and thermal strain, result in a decline of aerobic performance (Shirreffs and Sawka, 2011, Maughan and Shirreffs, 2008) and affect cognitive processes such as decision making in skilled based sports (Meeusen, 2014).

The ASCM evidence statements on exertional heat illness (Armstrong *et al.*, 2007) and fluid replacement during exercise (Sawka *et al.*, 2007) are categorised within levels of defined evidence according to the strength of recommendations. *Category A* is based on consistent and good-quality patient or subject-orientated evidence and *Category B* is based on inconsistent or limited-quality patient or subject-oriented evidence. Sawaka et al (2007) state that "dehydration increases physiologic strain and perceived effort to perform the same exercise task, and this is accentuated in warm-hot weather" and propose that cognitive performance can deteriorate in dehydration >2% of body weight, *evidence category B.* Exertional heat illness is a condition that all athletes aim to prevent, it is agreed that individual levels of susceptibility to this exist. Predisposing factors to this occurring (*evidence category B)* during exercise in extreme heat include, dehydration, high BM, and elevated urine specific gravity (Armstrong, 2007).

2.6. Fluid replacement and hydration guidelines.

Fluid replacement in sports has remained a priority topic of research in the sporting literature for many years. The most recent comprehensive evidenced based position statement regarding fluid and exercise hails from the ASCM (Sawka *et al.*, 2007), and more recently from Shirreffs et al (2011) review paper, with a particular focus on fluid and electrolyte needs of athletes. Hydration goals for athletes include pre-event hydrating to commence activity euhydrated, (consuming at least 5 - 7 $mL \cdot kg^{-1}$ at least four hours before exercise), maintaining hydration throughout activity and replacing excessive fluid lost with ~1.5 litres (L) per kilogram (kg) body mass lost (Sawka *et al.*, 2007). While it is recognised that fluid and hydration in 'team sports' has not been thoroughly investigated (Burke, 1997), the consensus within the body of literature appears to endorse the prevention of excessive dehydration (BM loss >2%) and emphasises the importance of developing individual fluid replacement plans (Sawka *et al.*, 2007, Burke, 1997, Burke and Hawley, 1997).

2.6.1. Hydration guidelines for cricket.

Hydration recommendations for team sports can be found in various reviews (Burke, 1997, Burke and Hawley, 1997, Montain, 2008, Shirreffs and Sawka, 2011) and position statements (Sawka *et al.*, 2007, International Olympic Committee, 2011), however no peer reviewed published guidelines pertaining specifically to cricket exist. The Australian Institute of Sport developed a cricket specific hydration guideline entitled "Fluid Facts for Cricket", referencing two of the key hydration studies that have been conducted in cricket players (Devlin *et al.*, 2001, Gore *et al.*, 1993).

2.6.2. Cricket match drinks rules.

Cricket is steeped in tradition and history. The "Marylebone Cricket Club" (MCC), founded in 1787 (Fourny *et al.*, 2005) is the cricketing body that holds authority on the laws of the game internationally, and it is there that national cricketing bodies turn to clarify the rules including 'drinks breaks' protocols, and rules determining when fluid intake is allowed during a match. The current laws allow drinks breaks (in a 50 over game) at approximately every 17th over per innings, and allow extra drink breaks under team captain and umpire approval. According to Burke & Hawley (1997) these rules differ from those pre dating the year 2000, having previously allowed just one drink break per session, with extra drinking opportunities at the umpire and team captains' discretion. It is likely that Burke & Hawley's (1997) recommendation for increased access to drinks during cricket matches was highly influential on the updated MCC drinks breaks laws.

2.7. Methods of hydration assessment.

Assessing hydration is not only key for optimising sports performance outcomes but also for monitoring health and safety. Blood and urine indices have been reported by Shirreffs (2003) to be useful hydration assessment methods**.**

2.7.1. Biochemical marker - blood haemoglobin and plasma osmolality.

Plasma osmolality measures the number of particles per kilogram of solvent (mOsm.kg^{-1}). As a reliable and precise measure it is considered to be one of the gold standards in hydration assessment (Cheuvront and Sawka, 2005, Oppliger and Bartok, 2002, Sawka *et al.*, 2007). It has been found to be sensitive enough detect acute hydration shifts arising from hypertonic dehydration resulting from sweating (Oppliger and Bartok, 2002) and is used as a criterion method in the accuracy assessment in other measures of hydration (Oppliger *et al.*, 2005). The disadvantage to this method of hydration assessment is that the technique is complex, expensive and invasive and impractical for repetitive hydration testing in athletes (Cheuvront and Sawka, 2005, Oppliger and Bartok, 2002, Sawka *et al.*, 2007).

Blood haemoglobin concentration is a suitable baseline hydration marker, however changes in blood volume can affect results; to control for this it has been suggested to standardise posture for a period of time prior to blood collection (Shirreffs, 2003). Mixed reports on its accuracy as hydration marker have been reported during periods of dehydration secondary to the human body's mechanism of plasma volume homeostasis (Shirreffs, 2003).

2.7.2. Urine markers.

Urine indices that are used as a hydration markers include the analysis for urine osmolality (U_{osm}), urine specific gravity (U_{sg}) and urine colour (U_{col}) (Shirreffs, 2003). U_{osm} and U_{sg} are a quantitative form of urinalysis. U_{osm} measures the concentration of solutes in urine, more specifically; the amount of osmoles of solute particles per kilogram of a solution (mOsm.L^{-1}) and U_{sg} measures the weight of the solute; the density of urine compared with water (Oppliger and Bartok, 2002). U_{col}, a qualitative biomarker of hydration status, is assessed via the use of a 6 - 8 point Likert colour scale (Oppliger and Bartok, 2002). Although reported as practical in its use, (Armstrong *et al.*, 1994, Armstrong *et al.*, 1998), subjectivity in interpretation has been reported as a confounding limitation inherent to this method (Sawka *et al.*, 2007). Ingestion of certain foods or supplements can also influence urine colour, however it has been found that the ingestion of vitamin B2 and B12 does not confound assessment in a euhydrated state (Kenefick *et al.*, 2015).

The ASCM report that U_{sg} is the best first morning / pre-event hydration status measure to use (Sawka *et al.*, 2007). Various U_{sg} reference values have been assigned to define euhydration (Armstrong *et al.*, 2010), however the ASCM report that ≤1.020g·ml^{-1} is indicative of being euhydrated (Sawka *et al.*, 2007). Urine indices are however not the most reliable measure to assess hydration during and after activity because of the rapid body fluid turnover that can occur during exercise (Shirreffs, 2003). Urine indices, such as U_{sg} require a period of stable hydration to accurately differentiate between euhydration and dehydration (Sawka *et al.*, 2007, Shirreffs, 2003, Turocy *et al.*, 2011). It has been suggested that U_{col} is appropriate to use in athletic setting where less precision is required and that U_{osm} can be used interchangeably with U_{sg} in the assessment of hydration (Armstrong *et al.*, 1994). Furthermore U_{sg} is easily measured by a portable refractometer, which is accessible and practical for use either in research or for individual monitoring purposes (Maughan, 2008).

2.7.3. Body mass changes.

The athlete assessment of fluid balance and hydration from BM (kg) change has been reported to be quick and effective (Sawka *et al.*, 2007), and suitable for use in the field (Harvey, 2008). This can be achieved from measurement of fluid gains and fluid losses, and from BM assessment on electronic scales that are sensitive enough to detect differences of 10-20g (Cheuvront and Sawka, 2005). The assumption applied is that 1 mL of sweat loss equals 1.0g of loss in body mass (Sawka *et al.*, 2007, Tam and Noakes, 2013). Any additional food intake or stool loss would need to be considered in BM change calculations (Baker, 2017). For increased accuracy, due to sweat in clothing, the pre and post exercise weigh would be taken unclothed (Maughan and Shirreffs, 2008, Sawka *et al.*, 2007), showering and towel drying before the post exercise weight (Maughan and Shirreffs, 2008) with voiding or defecating, taking place before the weight measurements if the urge is necessitated. A crude whole body sweat loss can also be estimated from this method (Maughan and Shirreffs, 2008, Baker, 2017).

A limitation with the BM change method is that it does not consider other smaller net body water losses via the respiratory route, or metabolic water production. Conflicting views on how to deal with this exist; Sawaka (2007) and Baker (2017) state that corrections for these losses are not required for exercise less than three hours, whereas Tam (2013) states that the degree of water gain and estimates via these routes will always vary due to individual factors and the environment (Tam and Noakes, 2013).

2.8. Hydration status of cricketers.

2.8.1. Observational studies.

The hydration status of cricket players during matches is largely unknown. However, two studies published 20 years apart observed the fluid intake and hydration status of cricket players during play; both conducted in Australia, in males (Gore *et al.*, 1993) and females (Soo and Naughton, 2007).

In an observational study Gore et al (1993) calculated percentage BM losses, fluid replenishment and measured sweat loss, during cricket in 20 first grade male cricketers aged 19-22 years. The study was conducted over three seasons (1988-1991) from three field experiments: two from simulated play under cool (22.1°C) and warm (24.5°C) temperatures, and one from an actual match, under hot (27.1°C) conditions. First grade cricket time intervals of two hours of play over three sessions of play were adhered to and study measurements were taken for each session and in total. Sweat rate, assessed by the change in body mass + drinks + food – urine – faeces / time, was calculated at the end of each of three sessions of play and in total. The mean total sweat rates were significantly different *($p<0.05$)* between all temperature conditions of play: 0.54, 0.70 and 1.37 $kg{\cdot}hr^{-1}$ on the cool, warm and hot days respectively. Significantly higher sweat losses (1.67 $kg{\cdot}hr^{-1}$) occurred during the hot day. The mean percentage BM losses at the end of the games were - 4.3% on the hot day versus - 1.2% and - 0.3% on the warm and cool day respectively. Fluid consumption matched sweat loss during the cool and warm day but not in the hot day. Despite the need for increased fluid, the players on the hot day did not drink more than the players on the cool and warm days. The authors suggested that this observation was an example of an athlete's maximal tolerated volume of fluid, and recommended increasing the frequency of fluid replacement during matches of extreme heat. It was concluded that dehydration to - 4.3% was a potential risk for heat illness and impaired physical performance. A recommendation to make modifications to the drinks rules to improve access to fluids at cricket games was made.

Soo & Naughton (2007) investigated hydration parameters in 18 female elite player level cricketers, over three one-day tournament matches. Similar sweat and body mass estimation equations to Gore et al (1993) were used, except urine loss was assessed by weighing players before and after toilet breaks and it did not appear that consumption of food mass was considered. Hydration measures were taken at the beginning and end of sessions of play and climatic temperatures were recorded over each match. A critical appraisal approach was applied during analysis to classify participants into high and low activity groups.

Pre-event hydration status was obtained via U_{sg} testing from the first morning void the first day of the tournament, resulting in a mean 1.022 g·ml^{-1} (range 1.009-1.029 g·ml^{-1}) which in accordance with the ACSM (Sawka *et al.*, 2007) indicated that some players did not start the match euhydrated. No significant differences between innings were found for mean fluid intake, sweat loss, sweat rate per hour or body mass percentage change. The average sweat losses per hour per innings were not excessively high but on the third and hottest day were significantly higher for participants within the high activity group. The matches occurred in different temperature conditions that gradually increased each day. While the recordings were much the same at those reported by Gore et al (1993), the female study participants did not produce sweat losses as large as those recorded by Gore et al (1993). Viable explanations for this might include that females by have lower sweat rates than males (Sawka *et al.*, 2007), data was collected across all playing positions (not only in batters and bowlers), and the average fluid intake was 250 ml.h^{-1}; less than half of the fluid intake that was calculated in the study of Gore et al (1993). The authors concluded that overall the fluid loss and sweat rate in this group was modest, and recommended development of individualised fluid rehydration strategies for players. A limitation to this study was that weight from food intake was not accounted for, and this might have resulted in overestimations of fluid and sweat loss.

2.8.2. Intervention studies.

Few studies have looked into the effects of hydration on cricket players and performance, the following section summarises two such studies that have.

In 2001 a group of Australian based researchers conducted a controlled intervention study aimed at measuring the effects of euhydration and dehydration on bowling velocity and accuracy in seven semi-elite male fast pace bowlers (Devlin *et al.*, 2001). As factors other than hydration itself might affect bowling performance, strict measures were taken before each trial to reduce potential for confounding factors. Blood haemoglobin concentration was taken as a pre-trial hydration status marker. Two trials (one where fluid was restricted and the other where it was not) took place seven days apart, the experimental protocol consisted of a warm up, six bowling overs, two shuttle run tests, one hour of intermittent exercise in a heated room, six overs bowling and a final shuttle test. In the euhydration trial participants were requested to drink coloured flavoured water, in the hypo-hydration trial participants were requested to drink coloured flavoured water and ice-blocks. Participants were led to believe the coloured drinks and ice blocks would improve their performance and were unaware of the different volume of fluid intake between trials. The trials resulted in a body mass deficit of 0.5% and 2.8% in the euhydrated and hypo-hydrated trial respectively. A significantly reduced number of shuttle runs and an impaired bowling accuracy (by line measures of 16.4%) resulted in the hypo-hydrated trial. There was no decline in overall performance in the euhydrated trial. This study highlighted the effect of infrequent fluid replenishment and 2.8% body mass losses dehydration on bowling performance. Delvin et al (2001) suggested that dehydration > 3% might impart further impairments in bowling accuracy.

Fifteen years later a cross-over design study tested the effects of dehydration on motor skill performance in bowling, batting and fielding in hot humid conditions in 30 international (Sri Lankan) representative male cricket players (Gamage, 2016). Two field trials, one of fluid restriction and one of fluid provision, consisting of two hours training and one hour of skills performance testing pre and post training took place seven days apart. Researchers controlled dietary and fluid intake and activity for the 48 hours prior to the trial. Pre and post-trial body mass (kg), U_{sg} ($g{\cdot}ml^{-1}$) and urine colour (scale 1-8) were measured to evaluate hydration. Temperature conditions were no different between trials (mean 30.8 °C and 30.1°C). The mean fluid ingestion ($ml{\cdot}h^{-1}$) was significantly lower in the fluid restriction trial (255 ± 47 $ml{\cdot}h^{-1}$) compared with the fluid provision trial (1148 ± 12 $ml{\cdot}h^{-1}$) ($p<0.05$), with a significantly higher mean body mass loss of 3.7% in in fluid restriction versus 0.9% in fluid provision ($p<0.01$). Results also indicated significant performance deficits in bowling and overarm throwing for accuracy by line (impaired by 19.8%) and speed, and for batsmen's time to run three runs in the restriction group. The paper concluded that the moderate to severe dehydration of 3.7% in hot humid conditions impaired motor skill performance, notably in bowler and fielders, and that a body mass loss ≤1% did not.

2.8.3. Hydration summary.

Cricket is performed over a prolonged duration, in heavy clothing, during summer and there are rules around access to fluids. Batters and bowlers that find themselves performing high intensity activity for lengthier periods of time under the conditions described above might be at risk of adverse outcomes associated with dehydration if preventative measures are not taken. In addition to this, two studies have demonstrated effects of dehydration on skills performance in cricket (Devlin *et al.*, 2001, Gamage *et al.*, 2016).

Despite the potential risks, less than a handful of investigations regarding hydration during cricket have taken place. The results are mixed, and show evidence of excessively high and of modest body mass percent losses. Historically there has been little opportunity to hydrate during a match, where as the modern day rules have become more relaxed with the MCC increasing access to fluids at games.

Current and up to date knowledge on the hydration status of cricketers before, during and post games is lacking and further investigation is warranted. Conducting hydration studies for cricket in the field is difficult without incurring high subject burden and game disruption. Until further research takes place it is likely that scientific investigations on fluid requirements for athletes from other sports will continue to inform cricket authorities on suggested best practice fluid replenishment guidelines. Further exploration into the hydration practices and status of cricket players before, during and after match time, would be of benefit to cricketing performance.

2.9. Anthropometry.

Gathering anthropometric data is an integral part of the nutritional status and health and performance assessment. Indirect measures of body composition body composition such as body mass index (BMI) ($kg{\cdot}m^{-2}$) are the simplest and most commonly obtained. BMI population ranges as determinants for health around weight status have been determined (Centers for Disease Control and Prevention, 2017). The inability to distinguish between fat mass and fat free mass from BMI calculations means that it is not possible to accurately describe individual or athletic populations' body composition (Thomas *et al.*, 2016), potentially misclassifying muscular athletes in BMI categories associated with unhealthy overweight (Centers for Disease Control and Prevention, 2017).

The skin fold measurement is a widespread technique used in athletes for routine monitoring of body fat levels in response to training (Thomas *et al.*, 2016). For team athletes there are known benefits to being 'lean' (Thomas *et al.*, 2016). Despite the efforts to standardise practice by the International Society for the Advancement of Kinanthropometry (ISAK), uniform application cannot be guaranteed (Thomas *et al.*, 2016). Sum of seven skin folds (S7SF) normative athlete reference data sets have been compiled, (Shaw *et al.*, 2015), however these may not be fully representative across athlete groups in different sports. Therefore extrapolating and interpreting fat percentage measures from sum of skin fold regression equations needs to be approached with caution. Although a small number of these equations have been cross-validated, it has been suggested that very few are reliable for use in athletes (Ackland *et al.*, 2012).

In a 2012 International Olympic Committee review and position statement, an extensive review of body composition techniques used in athletes was described and the expert panel recommended the use of a multi-component model for body fat estimation (Ackland *et al.*, 2012). From the multi-component models available they suggest dual energy x-ray absorptiometry (DXA) to be the most practical, measuring bone density, and fat mass with standard errors of estimate (SEE) of 2-2.5% (Ackland *et al.*, 2012). The 2016 ACSM Nutrition and Athletic Performance Position Stand (Thomas *et al.*, 2016) shares the same view, reporting DXA to be the gold standard for measurement, and when taken under standard procedures, to have the lowest SEE compared to skin folds which have the highest (Medicine. *et al.*, 2016, Thomas *et al.*, 2016). DXA has been available since the 1980's, initially measuring bone mineral content and density.

Advancements in DXA technology have given rise to improved measures of body composition thus providing more accurate, detailed (body segmental) and precise measures. No officially accepted normative body composition DXA data reference ranges for athletes exist as yet (Ackland *et al.*, 2012).

Table two provides a summary of the anthropometric measures available for use in athletes. Assessing body composition directly, (*level I*) can only be achieved on cadavers (Martin, 1991). Table two classifies the methods according to either indirect *(level II)* or doubly indirect *(level III)* methods. These methods were developed for living beings. *Level II* methods have been validated against cadavars, and *level III* methods against *level II* models; therefore, all methods are only as accurate as the underlying assumptions of which they are based on. Furthermore, the table describes the number of body components that are measured.

Table 2.2. Anthropometry and body composition assessment methodology in athletes.

Method	Description	Assumptions	Advantages	Disadvantages
Body Composition Laboratory Measures (Indirect assessment – Level II)				
DXA 3 compartment: measures FM, bone & FFM soft tissue.	Subjects lie horizontal on an X-ray scanning table. Xray beams attenuate body tissue material at differing photon energies.	• Does not factor in magnification errors & beam hardening that may exist.	• Quick & non-invasive. • Low level of subject involvement. • Small radiation doses compared to alternative x-ray machines. • Lowest standard error of estimate. • Precision & accuracy are 1-2%.	• Expensive & less accessible. • Requires a qualified skilled technician. • Results from very small or very large athletes may have increased error. • Different manufacturer models & algorithms may produce varied results. • No normative DXA athlete data exists. • Not suitable for frequent repeat monitoring of athletes.
Densitometry: UWW and ADP 2 compartment: measures FM & FFM.	Subjects follow a breathing / air exhalation protocol. From a measure of whole-body density, fat content is calculated. ADP: air displacement plethysmology: seated in a sealed air capsule (BOD-POD). UWW: underwater weighing on a submersible seat.	<u>UWW:</u> • Assumes constant densities of FM and FFM. <u>ADP</u> • Chamber thermal air properties are assumed. <u>UWW + ADP</u> • Assumes a constant density of FM & FFM within and between a population. • Residual lung & gastrointestinal air is estimated. • That equations are validated in each sample group.	<u>ADP versus UWW</u> • Lesser subject co-operation required and more practical than UWW. • ADP technology minimises ME – minimises trapped air that can occur in lungs or gastro-intestinal tract of UWW. <u>UWW + ADP</u> • Quick. • Reliable with high precision. • Ease of training operator.	<u>UWW</u> • High level of subject co-operation / water confidence and exclude subject if conditions of fluid retention exist. <u>ADP</u> • Under estimates body fat by 2-3%. • Accuracy dependent on: subject protocol compliance, subjects wearing tight fitting clothing and containing the capsule in a separate room tightly controlled for temperature and humidity. <u>UWW + ADP</u> • Expensive & less accessible. • Estimations from assumptions in FM / FFM increase ME. • FFM density assumptions in athlete population more likely to be erroneous (caution in lean athletes).
Body Composition Laboratory Measures (Doubly indirect assessment – Level III)				
Bioelectrical impedence analysis (BIA) 2 component: measures FM & FFM.	Subject stands on scales & follow easy instructions. Scales with electrodes: estimates FFM from measures of the electric current of total body water.	• Subjects are geometrically the same. • The current passes through all subjects similarly . • Tissue resistivity the same between individuals. • Subject compliance to standardized pre testing protocol.	• Quick & non-invasive. • Low level subject co-operation. • Immediate results. • Ease of training operator.	• Fat mass estimate influenced by electrolyte balance which is affected by exercise, food consumption & fluid intake. • Hydration status affects results. • Electrode placement can vary between models. • Trunk value under represented, limbs value over represented. • Little normative BIA athlete data exists.

Table 2.2. Continued. Anthropometry and body composition assessment methodology in athletes.

Method	Description	Assumptions	Advantages	Disadvantages
Anthropometry Field Measures (Doubly indirect assessment level III)				
Skin fold measurements 2 component: FM FFM estimate using Sums of skin folds equations.	Skin fold caliper technique compresses a double layer of skin at specific skin sites to calculate a sum of skin folds Regression equations applied to resulting sum of skin fold measures to estimate fat percentage.	• Measures subcutaneous fat only. • Assumes multiple assumptions relating to skin and fat for thickness, water content, compressibility and distribution as well assumption of constant density of FFM. • The fat estimation equations assumes that intra-individual FM and FFM densities are the same.	• Quick & non-invasive. • In-expensive and accessible • Proxy measure of changes of adiposity and muscularity in response to nutrition/training interventions. • Normative reference range data in athlete populations exist for sum of 7/8 skin folds in various athlete groups. • ISAK trained experienced testers yield more accurate and precise results. • Ability to monitor changes in 'estimates' of body fat over time and in response to training if standardised testing occurs with the use of same subject validated equations.	• Uniform standardisation of skinfold sites, measurement techniques and caliper 's cannot be guaranteed. • Highest standard of error of estimate. • Large number of regression equations to choose from • It may not be possible resource population specific prediction equations that have been cross-validated and reliable. • No guarantee that the normative reference ranges are representative.
BMI	Weight / height^2.	• Weight change as a result of FM. • Constant FFM to height .proportion. • Constant subject body segment proportions.	• Quick easy calculation.	• Cannot differentiate between fat & muscle. • Cannot compare results of subject ≥ 18 years to subjects < 18 years where BMI percentile is used. • Can misclassify muscled athletes into overweight categories.

ADP = Air displacement plethysmography. **BMI** = Body mass index**, BOD-POD** = (Life Measurement Inc., Concord, CA, USA), **DXA** =Dual Energy X-ray Absorptiometry, **FFM** = fat free mass, **FM** = fat mass, **ME** = measurement error, **SEE** = Standard estimate of error, **UWW =**Hydro-densitometry underwater weighing, *2.9.1. Anthropometric assessment of cricket players.*

Table three provides a selected summary from key papers highlighting studies that have investigated anthropometry in an attempt to define the physical characteristics common to cricketers. Where some studies have compared anthropometric results of cricket players to controls (Koley, 2011, Koley *et al.*, 2009, Micklesfield *et al.*, 2012, Stretch, 1987, Stretch, 1991) or between player positions (Johnstone and Ford, 2010, Stretch, 1991), others have been conducted with the view to provide reference values and somatotype identification to aid talent selection and guide strength and conditioning training programmes (Stuelcken *et al.*, 2007, Koley *et al.*, 2012, Stretch, 1991). The earliest anthropometric specific investigations in cricket were completed in the 1980's. Stretch (1991) compared the same number of cricketers from the 1989 - 1990 season, to a similar group of cricketers from the 1981 - 1982 season and found no significant differences in mean mass (83.3 kg and 82.9 kg respectively), height (1.8m on both occasions) or body fat percentage (10.3 and 9.3% respectively). In both investigations fat percentage was calculated from the seven skinfold measurement.

2.9.2. Height.

Cricketing height data tends to support the general view that cricket players are taller than the general population. Two recent studies (Lees *et al.*, 2016, Micklesfield *et al.*, 2012) found cricketers to be significantly taller than their matched controls. A review specific to profiling male fast bowlers reported that fast bowlers fell within a taller range (1.83 - 1.92m) compared to batters (1.76 - 1.85m), and to the mean value from Australian and English statistical data for the same population (1.70 - 1.77m) (Johnstone *et al.*, 2014).

2.9.3. Mass and body fat percentage.

Although low in participant study numbers, Lees et al (2016) and Micklesfield et al (2012) reported cricket players to be significantly leaner than matched controls, using the DXA technique. In the study of Mickelfield et al (2012), in first class South African cricketing males aged 16-34, no significant difference in weight was found, however lean body mass (61.4kg) was significantly higher when compared to controls (56.8kg). Whole body fat mass percentage was also lower (15.7%) than controls (18.4%) but this difference was not significant.

Sum of skin folds and skin fold equations have been the predominant study method undertaken to assess body composition of cricket players (Johnstone and Ford, 2010, Koley, 2011, Koley *et al.*, 2009, Stretch, 1987, Stretch, 1991, Stuelcken *et al.*, 2007). Body fat percentages in 70 South African and 471 Indian male cricket players from 1987 – 2012 have resulted in ranges from 9.3 - 17.7% from various skin fold equations (Koley, 2011, Koley *et al.*, 2009, Koley *et al.*, 2012, Stretch, 1987, Stretch, 1991). The limitations and assumptions of this methodology make it difficult to compare body composition across studies, however investigations on Indian cricket players (Koley, 2011, Koley *et al.*, 2009) comparing cricket player body composition to controls, similarly to the DXA study findings (Lees *et al.*, 2016, Micklesfield *et al.*, 2012) found that cricket players were leaner than their control counterparts.

2.9.4. Anthropometry summary of cricket players.

The typical anthropometric profile of high performance and competitive cricket players is difficult to describe. Available data spans three decades, over such a time that body composition assessment techniques have improved. Only two cricket studies of fast bowlers utilised DXA (Lees *et al.*, 2016, Micklesfield *et al.*, 2012). The existing anthropometry data is not highly representative across the globally and ethnically diverse range of high performing and competitive cricket players. Most studies capture data from males and the total number of study participants and assessment methods used have varied. However, it can be seen that a fairly high performing if not elite caliber of cricketers have been represented across the studies. While it appears cricket players may be taller and leaner than matched controls, and fast bowlers taller than batters, it is difficult to generalise these findings. Defining the body composition of cricket players would require larger-scale assessments across both genders, all player positions, from within all countries where cricket is played and using a gold standard methodological approach.

Table 2.3. Anthropometric profiles of cricket players

Author, year published & Country	**Participant no., gender, mean age, or range athletic caliber**	**Playing Position**	**Purpose**	**Methodology**	**Mean measurement results**					
					Ht (cm)	Wt (kg)	BMI	SF (mm)	BF (%)	BC
Anthropometric profile of first-class cricketers										
Stretch RA. 1987. South Africa.	35 M. 27.9 years. Prov & Intl.	All.	Identify morphological characteristics & compare to sedentary controls & between player positions.	Ht: harpenden. anthropometer Wt: seca beam balance scale. BC: 7 SSF & fractured body mass technique, (Drinkwater & Ross 1980) .	**Tt** 180.8 Bt 179.8, Bo 183.7, AR 179.7	**Tt** 82.9 Bt 81.7 Bo 83.5 AR 83.6			**Tt** 9.3 Bt 9.6 Bo 9.2 AR 9.1	**MM (%)** Tt 43.7 Bt 43.3 Bo 44.3 AR 43.3
Anthropometric profile and body composition changes in first class cricketers										
Stretch RA. 1991. South Africa.	35 M . Ages not known. Prov & Intl.	All.	Identify morphological characteristics common to Bt & BO & AR . Compare to Stretch 1987 & explore relationship of AP to performance.	Ht; Martin-type.anthropometer. Wt: beam balance scale. BC: 7 SSF & fractured body mass technique, (Drinkwater & Ross 1980).	**Tt** 180.8 Bt 176.4 Bo 187.3 AR 178.3	**Tt** 83.3 Bt 77.6 Bo 90.3 AR 88.8			**Tt**10.3 Bt 10.3 Bo10.4 AR 9.8	**MM (%)** Tt 45.2 Bt 44.8 Bo 46.1 AR 46.2
Anthropometric characteristics of elite cricket fast bowlers										
Stuelcken M et al . 2007. Australia.	26 M. 23.9 years. 26 F. 22.5 years. Elite & Intl.	Fast Bo.	Describe & establish AP reference values for talent identification & training development.	Ht; Stadiometer. Wt: DSS. 7 SSF + Somatotype (no BC).	M: 188.0 F: 171.0	M: 87.9 F: 66.2		M:62.3 F: 98.1 **S7SF**		
An association of hand grip strength with some anthropometric variables in Indian cricket players										
Koley S et al 2009 India	103 M. 18.3 years. Age range 17-21 years. District & state.	All.	Associate AP variables to hand grip strength & compare to matched controls.	Ht; Stadiometer. Wt: DSS. Triceps & subscapular skin fold calculated BC, (Wormersly & Durnin 1977).	174.4	59.3	19.8		14.0	86.0
Physiologic profile of professional cricketers										
Johnston JA et al. 2010. United Kingdom. Wales.	15 M. 25 years. Age range 21.2-30.5 years. FC PCC.	Bt, Bo.	Identify AP & physiologic profile of a professional cricket team and identify differences between playing positions.	Ht; Stadiometer. Wt: DSS. BC: S7SF.	**Tt** 183.0 Bt 181.0 Bo 185.0	**Tt** 81.1 Bt 72.5 Bo 83.5	**Tt** 24.1 Bt 23.8 Bo 24.2	**Tt** 69.7 Bt 65.5 Bo 72.5 **S7SF**		

Table 2.3. Continued. Anthropometric profiles of cricket players.

Author, year published & Country	Participant no., gender, mean age or range, athletic caliber	Playing Position	Purpose	Methodology	Mean measurement results					
					Ht (cm)	Wt (kg)	BMI	SF (mm)	BF (%)	Lean mass
A study of anthropometric profile of Indian-inter university male cricketers										
Koley S. 2011. India.	98 M. 21.0 years. Inter-University.	All.	Investigate AP profile & any correlations among results & compare to matched controls & across age groups.	Ht; Stadiometer. Wt: DSS. BC: S4SF + Slaughter et al 1988 equation.	171.0	61.8	21.09		15.8	
Anthropometric, Physical Strength, Body Composition and Performance Test Profiles of Inter-District Level Male Cricketers of Punjab, India										
Koley S et al. 2012. India.	271 M. Age range 21.0 – 22.8 years. Prov .	All.	Comparing measures to performance test variables.	Ht; Stadiometer. Wt: DSS. BC: 7 SSF & Siri's equation.	Total mean n/a: expressed as ranges					
					178-180.9	66.2– 72.6	21.0–22.7		13.8 – 17.7	**LM (%)** 55.6-58.4
Bone mineral density and body composition of South African cricketers										
Micklesfield LK et al. 2012. South Africa.	43 M. Age range 16-34 years. Prov & Intl.	Fast Bo.	Compare BMD & BC of competitive cricketers to controls.	Ht: Stadiometer. Wt: Electronic scales. BC: Dual-energy X-ray. absorptiometry (DXA).	180.3	77.8	23.9		15.7	**WBLM (kg)** 61.4
Total, regional and unilateral body composition of professional English first-class cricket fast bowlers										
Lees MJ et al. 2016. United Kingdom.	12 M. 22.6 years. Age range 17 – 30. FC PCC.	Fast Bo.	Determine advanced body composition profiles of elite fast bowlers with matched controls.	Ht: Stadiometer. Wt: Electronic scales. BC: Dual-energy X-ray. absorptiometry (DXA).	187.7	84.9	24.3		17.4	**LM (kg)** 67.0

All = batters, bowlers, fielders, all-rounders, **AP** = anthropometric, **AR =** all-rounders, **BC**: Body composition, **BMD** = Bone mineral density, **Bo** = bowling, **Bt** = batting, **DSS** = digital standing, **F** = female, **FC** = First class, **FC PCC** = First class professional county cricket, **Fld** = fielding, **G** = Gender, **Ht** = Height (cm), **Intl** = international, **LM** = Lean mass, **M** = male, **MA** = Mean age, **MM** = muscle mass**, Prov** = Provincial, **Tt** = total, **S7SF** = sum of 7 skin folds, **WBLM** = Whole body lean mass, **SF** = skin folds, **S4SF** = sum of 4 skin folds, **Wkt** = wicket keeper, **WT** = weight (kg).

2.10. Measuring Energy Expenditure.

For over a century scientists have been working on developing techniques for measurement of EE in humans (Ainslie *et al.*, 2003). Calculating EE is not an exact science, there is always some level of error, with this in mind careful consideration is required when choosing the most suitable method for research. This includes the number of measures sought (sample size), the time frame of which to take the measures, experience and capability of the research assistants and budget. Furthermore, one must take into account whether it is total EE or the activity EE that is being sought.

2.10.1. Doubly labeled water.

The doubly labeled water (DLW) method considered to be the gold standard for estimating EE in research, is not always the chosen method, due its high expense and need for specialised technicians. DLW can assess habitual energy expenditure in free-living subjects anywhere from 24 hours to three weeks, and typically over 7-14 days (Ainslie *et al.*, 2003, Hills *et al.*, 2014, Levine, 2005, Shephard and Aoyagi, 2012). As a criterion method, it is often used to validate other methods (Shephard and Aoyagi, 2012, Ainslie *et al.*, 2003), including physical activity questionnaires (Koehler *et al.*, 2010) and accelerometers (Maddison *et al.*, 2009, Plasqui and Westerterp, 2007). The DLW technique has been used to determine daily energy requirements within athletic populations (Ebine *et al.*, 2000, Hill and Davies, 2002).

2.10.2. Calorimetry.

Calorimetry; direct (DC) or indirect (IC) involves obtaining physiological measures of heat loss from the body or of gas exchange; oxygen consumption and or carbon dioxide production respectively (Ainslie *et al.*, 2003). Testing with calorimetry does have practical limitations, as subjects will be confined to a metabolic chamber (DC) or required to wear a mask, hood or mouthpiece (IC). Although the latter allows assessment in free-living subjects in observational studies, the wearing of apparatus might restrict the usual intensity of activity and movements that would otherwise or typically occur. Researchers have used IC to estimate EE in studies involving athletes (Bernardi *et al.*, 2007, Fletcher, 1955, Geesmann *et al.*, 2014). Applying this methodology in a test setting first, enables researchers to obtain individual EE values for different activity types, intensities and movements at varied power outputs for later applicability in field assessment and anlalysis.

2.10.3. Heart rate.

Using physiological measurements of the body as a means to estimate EE is well established, with researchers long ago uncovering that at submaximal intensities there is a linear relationship between heart rate (HR) and oxygen uptake (metabolic rate) (Berggren and Christensen, 1950, Booyens and Hervery, 1960). Although measuring HR via a portable device is cheap, and relatively burden free for the wearer, careful consideration of this application to estimate EE is warranted due to inter-individual variance (Achten and Jeukendrup, 2003, Leonard, 2003, Levine, 2005) and the numerous variables known to influence HR. Known variables include hydration, fitness levels, posture, genetics, gender, age, anxiety, environmental temperature and altitude (Achten and Jeukendrup, 2003, Ainslie *et al.*, 2003, Levine, 2005, Shephard and Aoyagi, 2012, Livingstone, 1997). In addition to this, measurements are reported to be less accurate at the extreme ends of activity (Leonard, 2003, Livingstone, 1997) and thus may suggest that it is less reliable method choice for estimation of EE during intermittent exercise. The consensus in the literature is that precision is improved when regression equations are developed and applied for individual subjects. Heart rate monitoring as a measure of EE is more applicable on a group than an individual level for the use of monitoring activity patterns and total EE (Achten and Jeukendrup, 2003, Ainslie *et al.*, 2003, Leonard, 2003, Levine, 2005). In sport, HR monitors are mainly used for determining the exercise intensity of the activity rather than assessing EE (Achten and Jeukendrup, 2003, Ainslie *et al.*, 2003). Considering the multiple factors affecting HR and the inter-individual variation, using HR to estimate EE in athletes during uncontrolled conditions of activity would be contraindicated.

2.10.4. Activity questionnaires.

Another method for estimating activity EE involves the use of validated activity questionnaires, recalls and diaries. These are completed by the subjects themselves and can provide a retrospective or current recall of activity. Activity questionnaires are typically used in large-scale epidemiological population health studies. The strength of activity questionnaires are that they can give detail on activity type and setting. Limitations with this method include subject recall bias, partial completion and or inability to record accurately (Brühmann *et al.*, 2014). Further to this, validity is dependent on matching EE reference tables that are specific to the particular activity and population in question.

2.10.5. Time-motion analysis.

Time motion analysis (TMA) is an investigation of athlete demands and movement patterns that occur over time during specific activities, and is used to define activity over games and matches (Watsford and Doğramaci, 2006). TMA analysis can be conducted via observation, recording or via the use of on body motion tracking sensors (Taylor *et al.*, 2017) and EE can be estimated from the TMA output data.

2.10.6. Direct observation and recording.

Historically sporting observations of movement have been collected and recorded via direct-observation, film or computerised time-motion analysis (Shephard and Aoyagi, 2012). Once observational data has been collected and recorded, individual EE can be calculated using the individual IC test values. In situations where individual IC EE test values are not available, the EE can potentially be calculated from activity energy cost reference data tables, from a compendium physical activity list that has been developed over many years (Ainsworth *et al.*, 2011, Ainsworth *et al.*, 1993, Ainsworth *et al.*, 2000, Herrmann and Pfeiffer, 2016). While this is a useful and simple method, it is not always possible to find data sets from a matched population (e.g. gender, age, ethnicity, sporting activity, recreational versus high performance) to generalise across, therefore an understanding of this as a limitation when reporting EE results is required. It has been suggested that the application of this is more suitable for epidemiological research where the outcome measures "categorise" activity intensity (Hills *et al.*, 2014). The compendium of physical activities has accumulated from a multitude of studies and population groups, most of which are non-athletic, and there is a lack of specific data reference available for high performance and competitive athletes.

2.10.7. Accelerometers.

Accelerometers are small electronic motion sensor devices, usually worn at waist level, that measure movement across 1-3 planes, vertical, anti-posterior and mediolateral (Hills *et al.*, 2014, Levine, 2005, Plasqui and Westerterp, 2007). Data from these can be plugged into regression equations to estimate EE. Large-scale epidemiological studies investigating physical activity and health outcomes tend to utilise accelerometers in determining activity patterns and intensity in large populations (Troiano *et al.*, 2008, Trost *et al.*, 2001). When used to estimate EE, the validity should be determined against a criterion method of either calorimetry or DLW (Jorgensen *et al.*, 2009). Experimental design studies have reported that accelerometers and associated equations were not as good a predictor of EE compared with IC (Crouter *et al.*, 2006) and DLW (Maddison *et al.*, 2009) and reported that activity intensity related EE were underestimated. A critique of 25 validity studies of three popular accelerometer activity monitor types concluded that EE was underestimated (Ryan and Gormley, 2013). The general consensus is that accelerometers do underestimate EE (Jorgensen *et al.*, 2009) and it has been suggested that further studies are necessary to develop improved EE assessment from accelerometers in smaller heterogeneous populations (Ryan and Gormley, 2013). Similar to HR monitoring, accelerometers are reported to be better predictors of EE at the group level (Levine, 2005, Maddison *et al.*, 2009, Ryan and Gormley, 2013) and thus less suitable to determine individual activity EE across varied intensity sporting activities.

2.10.8. Global position system.

Global position system (GPS) technology is a satellite based navigation system first discovered in the 1970's for use by National Aeronautics and Space Administration and has since been developed into small devices than can be worn to detect a person in position and time and quantify movement intensity and velocity. GPS was only relatively recently suggested for use in the field to monitor position and speed during sport (Larsson, 2003). It has since been used worldwide by professional sporting teams, in training and in games, providing TMA in outdoor sporting environments, with the capability of reporting activity profiles and player outputs for performance related analysis (Aughey, 2011) and fatigue monitoring (Aughey, 2011, Halson, 2014).

GPS has been described as the most effective and time efficient analysis method for the monitoring of team sports workload, but not without acknowledgement of the limitations. These include the potential underestimation of distance and speed in short bursts of high intensity activity (Vickery *et al.*, 2014a), and less accurate and reliable measurements from movements involving rapid directional change (Rawstorn *et al.*, 2014). Aughey et al (2011) conducted a review of multiple GPS validity sports studies and concluded that the validity was however improved when measures are taken over longer time periods, from large sample sizes and with the use of higher hertz models. An obvious practical disadvantage of GPS is that the units can only be used in team sports that are played outdoors, whereas advantages in the use of GPS in the field, are that the units are lightweight, don't interfere with performance, are robust and designed with increasing battery life.

A systematic review, from 2013, exploring the scope of GPS use within team sports, found work rate pattern to be the most common outcome measure reported, with the majority of research found within variants of football sports (Cummins *et al.*, 2013). Within the cricketing literature, GPS has been used to describe activity movement profiles during games (Petersen *et al.*, 2009b, Petersen *et al.*, 2010, Petersen *et al.*, 2011), in player fatigue assessment

(McNamara *et al.*, 2013) and in external training load analysis (Vickery *et al.*, 2017).

Manufacturers of GPS units have begun to include metabolic load analysis software from derived equations to support the calculation of activity EE. Metabolic power outputs derived from GPS units can be used in the calculations of energy cost. The advantages of using GPS TMA data to calculate EE over the original recording or computerized TMA methods, are that that acceleration and deceleration can be accounted for (Hull, 2018). This was made possible from the previous work of Osgnach et al (2010) in the development of a metabolic power equation that included both acceleration and deceleration. This science is relatively new, and the few reports on the use of GPS derived EE in the sporting literature have occurred in football (Woodruff and Meloche, 2013, Johnston *et al.*, 2015, Coutts *et al.*, 2015). A review of GPS metabolic power and energy cost in football reported large coefficient variations for acceleration, deceleration and distance from GPS, and GPS metabolic power output reliability was therefore questioned (Hull, 2018). The author cautioned against GPS as a reliable method of metabolic load and of energy cost in football due to the poor intra and inter-unit measure reliability that was found.

Table 2.4. Measurement of energy expenditure: methodologies available in athlete assessment.

Method	Description	Assumptions	Advantages	Disadvantages
		Physiological Measurements		
DLW Lab Non-lab	Measures CO_2 production. Subjects consume water containing stable isotopes and provide infrequent urine samples.	That CO_2 & $H_2 0$ & H_2CO_3 are in equilibrium.	• Highly accurate in determining free-living TEE for up to a three week period. • Validated against calorimetric methods. • Less subject burden and participation level required.	• Considerable expense involved. • High level of expertise in analysis. • High inter and intra subject variability. • Does not measure BMR, REE, thermic effect of food or differentiate between EE of specific PA bouts.
DC Lab	During testing subjects heat loss is measured during PA from within a metabolic chamber. TEE is estimated from the heat produced.	• Indirectly assumes the gas exchange equations measure heat loss.	• Accurate / precise for controlled experiments.	• Extremely expensive and less accessible. • Does not represent real life: conducted under laboratory conditions in controlled design studies .
IC – open circuit system Lab Non-lab	During testing subjects wear a hood or mask and mouthpiece during PA. TEE is estimated from published equations of the resulting gas exchange (O_2 consumption and CO_2 production).		• Portable devices can be worn by subjects for measurements outside of lab during exercise. • Can measure TEE, BMR, REE, thermic affect of food and specific PA's under controlled conditions for extrapolating to known body movements recorded in the field.	• Expensive and less accessible. • High subject burden wearing apparatus, hence can affect athlete's typical physical activity. performance in lab or non lab setting.
Heart rate Lab Non-lab	Heart rate monitor device measures heart rate and correlates it to EE.	• A linear relationship between heart rate and oxygen uptake.	• Quick and non-invasive. • Low level subject co-operation.	• High error reports when validated against DLW. • Because of varied fitness levels accuracy requires simultaneous measurements of HR & VO_2 from IC in a variety of activities for each individual to be able to improve accuracy • Other factors can affect HR: internal (physiological) dehydration, posture, illness, anxiety & external (environment) e.g. temperature, humidity.

Table 2.4 continued. Measurement of energy expenditure: methodology's available in athlete assessment.

Method	Description	Assumptions	Advantages	Disadvantages
Physiological observations: Kinematic (movement) measurements				
Activity questionnaires	A short assessment tool to assess physical activity, completed by the respondent.	• Accurate self reporting of activity.	• Low cost. • Simple to administer in small & large sample sizes). • Low – medium subject burden.	• Reliance on energy tables for EE conversions that not be well matched. • Dependent on subject honesty.
Direct observation & recording	Subject movements are recorded via: naked eye, film or computer movement analysis recordings. Energy cost of PA is computed utilising published standardised tables developed from previous calorimetric measures.	• That energy costs of various PA's are the same between subjects (unless it was quantified for each subject independently using IC).	• Non interfering: no subject burden. • Less expensive and more accessible than physiological measurements. • Can use if free living and assesses real life unaffected movement (during games).	• Time consuming for recorder / assessor. • Reliance on energy tables for EE conversions .that may not be well matched. •
Accelerometer	Small sensor device worn at the hip tracks and records intensity, duration and frequency of PA. EE computed from developed regression equations validated in laboratory conditions.	• That acceleration is proportional to muscle forces.	• Low to medium cost: device and software. • Assess real life movement (during games). • Can utilize in or outdoors. • Low subject burden allows freedom of movement.	• Can overestimate slower sedentary PA. • There are multiple regression equations in use. • Cannot use in watersports.
GPS	Satellite based navigation system. Calculates position, distance and velocity of movement over an epoch. Relative metabolic load (MET) outputs multiplied by weight calculate individual EE.	• That GPS output are an accurate analysis of activity.	• Can track in air, water and land. • Provides 3 dimensional movement data. • Moderate cost: device and software. • Low subject burden allows freedom of movement (non bulky and comfortable). • Assesses real life movement (during games).	• Limited battery life. • Cannot be used indoors / watersports • Cannot measure impact / contact. • Underestimates higher velocity movements.

Accel = accelerometer, **BMR** = basal metabolic rate, **DC** = direct calorimetry, **ME** = measurement error, **DLW** = Doubly labeled water**,** Isotope dilution, **GPS** = Global positional device, **IC** = indirect calorimetry, **Lab** = laboratory setting**, Non-lab** = non laboratory setting**, PA** = Physical activity, **REE** = Resting energy expenditure, **TEE** = Total energy expenditure.

This table has been compiled from: Heart rate monitoring – applications and limitations (Achten and Jeukendrup, 2003), Estimating human energy expenditure – a review of techniques with particular reference to doubly labeled water (Ainslie *et al.*, 2003), Dietary assessment of athletes: clinical and research perspectives (Deakin *et al.*, 2015), Measurement of energy expenditure (Levine, 2005), Measurement of human energy expenditure with particular reference to field studies: an historical perspective (Shephard and Aoyagi, 2012).

2.11. Physiological demands, energy intensity and energy cost in cricket.

Crickets games, referred to as matches are played between two sides consisting of 11 players and one 12th man (emergency player for injuries) per side (Shirreffs, 2003, Lord's the home of cricket, 2017, Sports Dietitians Australia, 2017). In one-day cricket two innings per side per match are played, limited to 50 overs, (entailing six legal bowls per over), and can last up to 6 hours (Berggren and Christensen, 1950, Lord's the home of cricket, 2017, Sports Dietitians Australia, 2017). An innings is completed when the batting side is all out, at the completion of 50 overs or at the fall of a wicket when no further batsmen are available (Lord's the home of cricket, 2017). Players are categorised according to their specialist-playing role: top order batter, pace or spin bowler, wicket keeper or an all rounder. All 11 players are scheduled to bat, however lower ranked batters may not bat if the innings or game ends before their order. All 11 players partake in fielding with one keeping wicket (Sports Dietitians Australia, 2017, MacDonald *et al.*, 2013a). The literature reports that wicket keepers take 21% of all fielding contacts (MacDonald *et al.*, 2013b). There must be five dedicated bowlers (or all-rounders) per side, each permitted to bowl 10 overs. The power play rule was introduced into the limited over cricket formats in 2005 to encourage fast pace aggressive batting and run scoring (Silva *et al.*, 2015). In essence a power play imposes fielding restrictions in a block of overs. Fielding positions occur close to the pitch in the slips, within the infield and within the outfield. Although yet to be defined, a high aerobic fitness along side varying degrees of strength have been reported as fitness requirements within different fielding positions (MacDonald *et al.*, 2013a). One-day cricket matches close at the completion of overs or when a run score has been succeeded (Lord's the home of cricket, 2017).

From the few studies that have investigated the physiological demands of cricket, most have focused on bowling, some batting (Scanlan *et al.*, 2016) and few in fielding (MacDonald *et al.*, 2013a) and wicket keeping (MacDonald *et al.*, 2013b). Investigations have analysed external demands, such as working load during games from TMA, or internal demand measures from physiological response parameters of interest, in cricket simulation studies.

External demands such as match intensity and movement quantification have been researched from TMA of cricket players in fielding (Rudkin and O'Donoghue, 2008), batting (Duffield and Drinkwater, 2008), and across player positions in different game formats (Petersen *et al.*, 2010, Petersen *et al.*, 2011). From computerised TMA of 27 in-fielders during 10 overs in first-class multi-day cricket, Rudkin et al reported high-intensity activity accounting for 1.6% of the fielding time. The authors acknowledged that large distances (15.5 km) were covered but described the fielding component of first class multi-day cricket as undemanding overall (Rudkin and O'Donoghue, 2008). In film TMA of 26 elite international level batsmen, an Australian research group reported no significant differences in movement patterns in the time spent within the various speed categories from batting centuries in one-day or test cricket. The authors reported that century scoring batsmen partake in high intensity activity much the same as in other repeat-sprint team sports, but spend most of their overall match time in low intensity activity (Duffield and Drinkwater, 2008). Concluding statements suggested that the information was useful to develop training practices that prepare cricket players for batting centuries and no conclusions were made with regards to the physiological demand imposed (Duffield and Drinkwater, 2008).

Two years on, a separate Australian research group set out to compare high performance cricketers' movement patterns and differences in workload via GPS technology. This study looked across all playing positions and three formats of play; multi-day, one-day and 20-twenty (Petersen *et al.*, 2010). Peterson et al concluded that the physiological demands between different playing positions and game formats varied immensely, with the shorter formats of play being higher intensity, and multi-day demanding a greater physical load. This study found that fast bowlers covered more ground in the faster velocity (stride and sprinting) bands, with the lowest work to recovery ratio compared to other playing positions across all formats. The average distance covered in one-day cricket players in the sprinting band (≥5.01 $m{\cdot}s^{-1}$) was 316 $m{\cdot}s^{-1}$ for fast bowlers, 149 $m{\cdot}s^{-1}$ for batsmen, 81 $m{\cdot}s^{-1}$ for fielders, 58 $m{\cdot}s^{-1}$ for spin bowlers and 34 $m{\cdot}s^{-1}$ for wicket keepers (Petersen *et al.*, 2010). The authors concluded that cricket is a low intensity game that includes intermittent short sprint movements.

Variables of interest related to health and performance that have been investigated in cricket, include physical fitness, strength, accuracy, core temperature, heart rate, blood glucose and blood lactate. These variables have been measured and reported in bowling (Burnett *et al.*, 1995, Duffield *et al.*, 2009), batting (Christie *et al.*, 2008, Christie and King, 2008, Pote and Christie, 2014), bowling and batting (Gore *et al.*, 1993, Johnstone and Ford, 2010) and across all cricketing positions (Vickery *et al.*, 2014b, Vickery *et al.*, 2013). Most of the above studies have investigated such variables in relation to health, fatigue and performance, and in general, have not made inference about the physiological demands in cricket *per se*. However from the investigations referenced above, two studies measured energy expenditure (Christie *et al.*, 2008, Pote and Christie, 2014).

2.11.1. Cricket studies: energy expenditure as an outcome measure.

It is difficult to accurately estimate the energy cost during a sporting event and challenging on a practical level. Regardless of the format played, how a cricket game plays out in terms of time and activity is almost always uncertain and unpredictable. It is not surprising therefore that very few studies investigate EE as a research outcome in the cricket scientific literature. In addition to this lies a long held historical belief that cricket is less demanding a game than others, and so it may not have been a high priority research interest in the past. Without rigorously conducted studies, long held historical beliefs regarding energy expenditure in cricket can still exist.

The extent to which the scientific literature has attempted to assess the actual EE of cricketing activity can be seen in table five. The earliest study investigating EE of cricketers during a game was completed 60 years ago (Fletcher, 1955). Oxygen consumption and EE of four players in the nets was assessed using a portable calorimeter. This information was combined with the times that two players spent in various physical activities during an intercollege match and EE was calculated per hour. From this methodology, activity at the nets was found to be as high as that of tennis, but overall match EE was found to be comparable to that of walking. Fletcher et al (1955) then calculated the 'average' EE of a 'hypothetical' player during an international test series. Observed recorded TMA of different types of activity across fielders, batters and bowlers was collected over 100 hours of international test data and converted into kcals per sq. m. per hour and the mean taken. The resulting average EE of a test cricketer was calculated and reported to be as low as 86.4 $kcal \cdot m^{-2} \cdot h^{-1}$, (650 $kJ \cdot m \cdot h^{-1}$ assuming a body surface area of $1.8m^2$). Fletcher et al (1955) concluded that the average test cricketer uses a relatively small amount of energy during a game. This study was in 1955, and a number of assumptions in calculating the energy cost from observations would need to have been made, for example attributing the same velocity to observed activity categories of standing, strolling, walking and running.

Fast forward 50 years, and two investigations were conducted six years apart using portable IC to measure oxygen consumption and subsequent EE during experimental protocols of simulated cricket game batting sessions (Christie *et al.*, 2008, Pote and Christie, 2014). These studies were similarly designed with the exception of the running and rest protocol; participants ran 14 more shuttle runs in the second study but with five and 15 second longer rest periods between balls and overs respectively. In the first study (n=10) conducted outdoors, an average EE of 2536 $kJ \cdot h^{-1}$ was reported (Christie *et al.*, 2008). The second experiment (n=12), was conducted indoors, the energy cost estimated from Pote et al (2014) was just slightly higher, 2776 $kJ \cdot h^{-1}$, compared to the earlier experiment of Christie even though less shuttle runs took place in this protocol. Pote et al (2014) suggested that the higher EE in the earlier study may have been a result of the running protocol differences between studies. In the first study double shuttle runs required turning action and may have consumed more energy. In both studies the EE results were higher than the batting EE that was reported by Flethcher et al (1955) 650 $kJ \cdot m^{2} \cdot h^{-1,}$ (1170 $kJ \cdot h^{-1}$ assuming body surface area of 1.8m^2). However study design differences, do not allow direct comparisons to be made.

Table 2.5. Energy expenditure studies in cricket.

Author, year published & Country	Participants				Position measured	Game Format Study protocol	Methodology	Measurement results
	Gender	Mean age year/month	No.	Athletic caliber				Mean EE
Fletcher JG 1955. England.	Male	n/a	n/a	Inter-college & elite international.	BO, Bt, Fld	Baseline in nets EE assessment, & EE assessment of movement categories in young men. Conducted prior to collection of match 'time spent' observational data during the 1953 English Test series against Australia.	Baseline EE: n = 4 at nets: portable calorimeter O_2 consumption. EE calculations from 'time spent' in playing positions from 100hrs of elite intl test data & EE calculated. Computed a mean EE of a "hypothetical" individual test cricketer.	• 650 $kJ{\cdot}m^{2}{\cdot}h^{-1}$ Bt. • 531 $kJ{\cdot}m^{2}{\cdot}h^{-1}$ BO. • 368 $kJ{\cdot}m^{2}{\cdot}h^{-1}$ Fld. • 361.5 $kJ{\cdot}m^{2}{\cdot}h^{-1}$ Match.
Christie CJ et al 2008. South Africa.	Male	22 .0	10	University cricketers.	Bt	Simulation*: Outdoor Runs: faced 7 overs/42 deliveries. Runs: 2 shuttle runs every 3rd ball = total 28. Rest : 30sec/ball & 60sec/over.	Continuous across $k4b^2$ EE calculated from O_2 consumption.	• 2536 $kJ.h^{-1}$. • kJ/single run = 98.
Pote L & Christie JC. 2014. South Africa.	Male	21.6	12	University cricketers.	Bt	Simulation **: Indoor faced 7 overs/42 balls, Runs: 1 shuttle every ball = total 42 Rest: 35sec/ball & 75sec/over	Continuous across $k4b^2$ EE calculated from O_2 consumption.	• 2776 $kJ.h^{-1}$. • kJ/single run = 66.

Bt = batting, **BO** = bowling, **k4b²** = indirect calorimetry metabolic system, **Fld** = fielding, **sec** = seconds, **n/a** = not available.
Simulation * developed from observations of 1-day matches from high scoring One-day internationals x 7 & Indian Premier League games from the 2010 calendar (≤260 runs).
Simulation ** developed from observations of 1-day matches from 1999 cricket world cup & specific international innings 1991-2001. (≤260 runs)

2.11.2. The demands of cricket: opinions.

In a review by Noakes and Durandt (2000) on the physiological requirements of cricket it was suggested that EE, with the exception of fast bowlers, is relatively low (Noakes and Durandt, 2000). They came to that conclusion by looking at exercise intensity, and comparing the heart rates and blood lactate of cricketers from measures reported by Gore et al (1993). When Bartlett (2003) conducted a comprehensive review on the demands of cricket players in batting, bowling, and fielding, he concluded that that the fitness demands of the game are not at all certain.

2.11.3. Energy expenditure in cricket - summary.

To date no other research has attempted to look at the EE of a cricketer over the duration of an entire 'live' game since the much earlier works of Fletcher et al (1955). Due to evolving game formats and increased demands on players it is possible that the energy cost of cricket-matches are different in modern day cricket. Further more, Fletcher et al (1955) investigated Test-cricket, which has since been identified as more endurance based compared to the other formats (Petersen *et al.*, 2010). Thus the mid 20th century claim that cricket was a game of low EE, (Fletcher, 1955) might be disputed in the current era. While the energy cost during cricket games has not since been investigated, cricket workload (from film, computerised or GPS TMA) has. In general the reports are suggestive that intermittent high intensity workloads with some element of endurance may exist within cricket matches. Of the two studies investigating EE in batting (Christie and King, 2008, Pote and Christie, 2014), both reported higher EE than that of Fletcher's in 1955. Others in agreement with Fletcher et al (1955), that cricket is a lowly demanding sport, arrived to their opinion from TMA studies in fielding (Rudkin and O'Donoghue, 2008) and from a review of heart rate responses in bowling and batting (Noakes and Durandt, 2000).

2.12. Summary.

Knowledge on the specific contribution of energy systems during particular activities informs sporting nutrition practices and strategies. Studies investigating the physiological demands of cricket players thus far have not related the demands back to nutrition. There is a paucity of well-researched literature investigating the EE of cricketers during matches, less than a handful investigating hydration and no reports in the literature on the dietary and energy intake of cricket players during games. What is clear is that different work rates and physiological demands across playing positions over different match formats do exist and the unpredictable nature of the game make the inquiry into energy expenditure very challenging in the sport of cricket.

Without further investigations during match time it is difficult to make accurate statements about the energy cost of cricket during a cricket matches. To begin to understand the requirements of a sport, there must first be observation and information gathering during the sporting activity. As no studies to date have investigated the dietary and energy intake prior to and during cricket matches this research will endeavor to do so with the view of identifying if there are any nutritional issues that need to be addressed for the future. MCC drinks rules still largely govern fluid replenishment hydration practices, and given the dehydration risk factors that can present in cricket, it seems prudent to investigate pre-game and end of game hydration. It is the hope that this study will provide a comprehensive picture around nutrition, energy and hydration parameters in 50-over cricket match games.

3.0. Methodological procedures.

3.1. Study design.

An observational and descriptive quantitative study was designed to assess energy expenditure during one-day 50-over cricket games and report on the before and during match dietary and energy intake, nutrition practices and hydration status of cricket players participating in these games.

3.2. Ethics.

Ethics approval was obtained from the Massey University Human Ethics Application Committee for the following application: HEC Southern A Application – 15/46 (MUHEC) and was accepted on the 10 August 2015.

3.3. Study target population.

3.3.1. Setting.

In New Zealand there are six cricket associations (Northern Districts, Central, Auckland, Wellington, Canterbury, Otago) from where the competitive (domestic) and elite (professional) teams arise. From these Auckland is a major Cricket Association. Within the Auckland Cricket Association (ACA) there is one professional first class men's team and three high performing competitive teams. The study aimed to recruit cricketers from the ACA competitive teams. The competitive teams include the men's "A" team, (the team one tier down from the first class side), the Women's domestic team, named "The Hearts", and the competitive "Developing Future Aces" (DFA) team, consisting of 16-19 year old males from within the Auckland development programme.

3.3.2. Auckland Cricket approval.

The research proposal and study target participant group was discussed with the ACA High Performance Manager in advance of the 2015 - 2016 cricket season. The ACA High Performance Manager granted permission and access to players. Invitations were extended to male and female cricket players ≥16 years from the A's, Heart's and DFA teams.

3.4. *Study organization.*

The study was organised into four phases:

- *Phase one*: Introduction to the study and recruitment in August 2015.
- *Phase two*: Baseline characteristic and demographic data collection during September 2015 at the Massey University Human Nutrition Research Unit (MUHNRU). The visit was specifically scheduled for the month preceding the official competition start period.
- *Phase three*: Field data collection at competitive one-day match fixtures from November 2015 – April 2016.
- *Phase four*: Data analysis.

3.4.1. *Phase one: Recruitment, planning and consent.*

Players were initially informed of the study by their respective coaches. Participation was voluntary, and players were informed that non-consent or withdrawal at any stage of the study would not negate player opportunities in the cricket season ahead. The lead researcher introduced and disseminated study information sheets (appendix A) and collected voluntary signed consent (appendix B) during ACA pre-season team training sessions held in the lead up period to competition games. Prior to consent, the players were briefed on what participation would entail and informed they might be observed during games on more than one occasion during phase three of the study.

3.4.2. *Phase 2: Demographics and characteristics.*

Participant demographic and physical characteristic parameters were collected during a single visit to the MUHNRU in September 2015. A pre-MUHNRU visit reminder and instruction email was sent to players (Appendix C) and appointment times were confirmed via email, or via text message if unconfirmed from email. General participant health information including age, gender, ethnicity and overall dietary practices were collected via a demographic, health and lifestyle questionnaire (Appendix D). Anthropometric assessment was undertaken for all participants. This involved measuring body height (to the nearest 0.1 cm) from a harpenden stadiometer (Holtain Ltd, United Kingdom) and weight (to the nearest 0.1 kg) via bioelectrical impedance analysis (Inbody

230, Biospace co. Ltd). Body mass index (BMI) was calculated by dividing weight (kg) by height squared (m^2). BMI percentile was estimated from the United Kingdom cross-sectional reference data for participants <18 years of age. Body fat percentage was collected and analysed by qualified DXA operators using Hologic QDR Discovery (Hologic Inc, Bedford, MA, USA) dual-energy x-ray absorptiometry and APEX V. 3.2 software .

3.4.3. Phase 3: Field data collection protocol, planning and documentation.

Game interference and participant burden were considered and discussed with the ACA coaches in the development of phase three data collection protocol. Player schedule and batting order were confirmed one week before each fixture. The distribution of study packs to scheduled participants containing instructions (appendix E), food diaries (appendix F) and urine collection bottles, were arranged at this time. Up to four research assistants (RA's) per game with nutrition and sports science expertise supported the lead researcher in data collection at the 50-over games. The lead researcher developed a field protocol for data collection that outlined a set list of defined tasks according to the RA's skill set. Observation and recording duties occurred through the length of the game with data collection commencing from the time the players arrived (pre warm-up) to the end of their game. As the end of game time can vary between players, the end of game time for each participant was defined according to the following:

1. Batting second innings: End of game was determined for each batsman as the time they got out, at the end of the first innings for the 12th man, or at the close of the match for batsmen that did not get a chance to bat.
2. Fielding second innings: End of game was defined as the same time for all players at the close of the match.
3. For any injured player who withdrew from the match, the end of game was defined as the time they were withdrawn from the match.

3.4.4. Match time keeping recording.

Batting order was documented prior to the game, if changes in batting order occurred the coach informed the lead researcher. The batting form (appendix G) recorded batting beginning and end times and pre and post batting RPE scores (not reported on in this study). During the fielding innings, one RA was assigned to keep a running record of bowling order and overs with one bowling over recorded per line (appendix H). These bowling and fielding inning forms, alongside copies of the official score sheets were referred to and cross checked against GPS download output data to double check key match times.

3.4.5. Game characteristics data collection.

Time and climatic conditions were recorded on designated forms each innings (appendix I). Temperature and humidity were taken from a portable weather station, (Aercus; model WS2083, West Yorkshire, United Kingdom) at eight set time points. These were at the beginning and end of both innings and at the 17^{th} and 34^{th} over (~ every 70 minutes in line with drink breaks) with the exception of games that ended within a shorter duration, in which case less measures were available to record. The game temperature averages were categorised from a climate science perspective as either warm, 20-24.9°C or hot, 25.0-29.9°C (P Pearce [National Institute of Water and Atmospheric Research] 2016, pers. comm., 19 December).

3.4.6. Early moring pre-match hydration assessment.

Participants collected a mid-stream urine (MSU) sample from their first morning void and brought it to the game. A portable refractometer (ATAGO SUR-Ne, Cat. No. 2734, ATAGO CO., LTD, Tokyo, Japan), calibrated in accordance to the manufacturer's instructions before testing at each game, was used to measure the U_{sg} of the samples in order to determine early morning pre-match hydration status and U_{sg} test results were recorded (appendix J). Urine specific gravity hydration cut offs applied were ≤1.020g·ml^{-1} euhydrated, dehydrated 1.021-1.030 g.ml-1, dehydrated and ≤1.031 g.ml-1, very dehydrated (Oppliger *et al.*, 2005).

3.4.7. Urine collection.

Participants were asked to collect all urine following their first morning void and until the end of their game. Urine collection bottles were collected at two time points: when participants arrived at the match (pre warm-up) and at the end of their game. Urine was measured in a measuring jug to the nearest 10 ml and recorded (appendix J) before being appropriately discarded.

3.4.8. Diet records.

The lead researcher and at least one RA (experienced and qualified in dietary assessment) oversaw the diet observation and recording at each game. Players commenced food recording from 10pm the night before up until they arrived at the match and arrived with at least 30 minutes before the warm-up for the pre-match study data collection. On arrival participant's produced their completed pre-match food and fluid diary, (appendix F) and brief diet assessment interviews were conducted to ensure the accuracy of records, corrections were made if indicated. All food and fluid consumed from time of arrival to end of game was recorded on a separate match food record (appendix K). Additional foods, snacks and drinks (extras) brought to the game were viewed, recorded and photographed on arrival. Over the course of the day, participants were closely monitored with regards to consumption of "extras" and being aware of the research protocol themselves, disclosed if and when "extras' were consumed. Final overall consumption of "extras" was confirmed at the end of the match from sighting and photographing "extras" left over alongside a brief final dietary interview. Participants were instructed not to consume post match food and fluid until this process was complete.

3.4.9. Match lunch.

Lunch provision was the responsibility of the host team. Players could choose to bring their own lunch if they preferred. At lunch break time, the participants collected lunch in a structured manner and observations of the foods players selected were recorded. In addition to written records, participant food and drink selections (including first and second helpings) were photographed alongside study identification labels placed in view of the camera immediately before being eaten. Any left overs, were also captured via photography.

3.4.10. Match fluids.

Water provision was the responsibility of the host team. If bottled water was provided, the lead researcher labeled multiple bottles for each participant and replaced as needed. When empty drinking vessels were provided, an initial vessel volume assessment was conducted, before labeling one bottle per participant and filling with water, and refilling as required. Volume assessment of partially full bottles was made possible from measuring the left over water volume in measuring jugs to the nearest 10mls and subtracting from the known vessel volume. The lead researcher was solely responsible for water and drinks monitoring. Fluid intake was captured on the match diet record (appendix K). Water provision, volume assessment and fluid consumption records were maintained from arrival through to end of game. Separate water bottles were provided for non–participant consumption and for body cooling purposes. At each match the water runners (who were either participant or non participant cricket players) were briefed and instructed on the drinks and water protocol to ensure that study participants were only supplied and drinking from their identified drinking water bottles. The study participants had been briefed on the drinks protocol at ACA training sessions, and were reminded again of these as they arrived to matches. Volume assessment took place at the arrival, beginning and end of innings and during lunch. Study participants also handed drinking vessels to the research team over the match period for volume assessment.

3.4.11. Body mass (weight) recordings.

Body mass assessment was taken from participants in light clothing (undergarments only) while standing on a calibrated electronic scale (Tanita THD646, Tanita Corporation of America Inc, Illinois, USA) on a hard flat surface and measured (to the nearest 0.1 kg). Measurements were taken on arrival, pre match: weight1 (Wt1) and at the end of match: weight 2 (Wt2). Participants only voided before Wt2 if they were in a definite need, otherwise they were weighed immediately at the end of their game. Post match food and fluid replenishment was withheld until after Wt2.

3.4.12. Global positioning systems.

Lightweight Global Positioning Systems units with a sampling frequency of 10 Hz and built in 16G accelerometers (SPI HPU GPSports, Canberra, Australian Capital Territory, Australia) were used for gathering distance, speed and time movement data (TMA). Units were cased between the shoulder blades within a specially designed vest worn under cricketing attire. They were placed on the players immediately post Wt1, switched on pre-warm up and turned off and removed immediately at the end of the participant's game time.

3.5. Data Analysis.

Describing 50-over cricket match times and player match times

Reporting game match times and player match times are defined as the following:

- Batting innings duration = time spent in bat.
- Fielding innings duration = time spent in the fielding innings, regardless of positions of play.
- Game time = total fielding time + total time spent in bat.
- Match time = warm-up time + lunch time + total fielding time + total time spent in bat. (*GPS match analysis did not include lunch-time*).

3.5.1. Descriptive nutrition data assessment.

Descriptive dietary information was reported pre-match and during the match. Pre-match dietary intake was reported as consumption via four food groups: vegetables and fruit; grain foods; milk and milk products; and legumes, nuts, seeds, fish, seafood, eggs, poultry and red meat (New Zealand Ministry of Health, 2015) and as a percentage of participants consuming each of the food groups. Foods and beverages were counted as being consumed once regardless of the amount consumed, eg. 50ml or 750ml of milk counted as consumption of milk. Food selection at lunch depended on availability, and an overview of food options provided at each game was reported. The consumption of extra foods snacks and beverages (other than lunch) at the match was summarised and described as “extras”.

3.5.2. Dietary data entry.

The lead researcher entered and analysed dietary data using the New Zealand and Australian Foodworks database (Foodworks version 8, Xyris Software Pty, Australia). Water consumption recorded at the games was also entered into dietary analysis. To determine the nutrient and energy intake from food and fluid, pre-match food and match food diaries were entered separately for each participant. Amounts were entered as gram, ml, serving size or household measure estimates. For consistency in data entry, standardised entry methods were applied. If the brand of a packaged food was not represented in the database, an appropriate substitute (determined from label reading and finding the closest match) was used. When brand names were not specified i.e, milk or bread, a consistent matched brand from the database was chosen throughout. Where a sandwich franchise was used, the standard ingredients and amounts in each sandwich and serve size information was sourced from the franchise outlet and entered as a recipe so the amount consumed could be entered as a serve size or part thereof. Where independent caterers provided lunch, the recipe ingredient information was collected on the day, and entered into the New Zealand and Australian Foodworks programme.

3.5.3. Quantitative nutrient and fluid analysis.

Foodworks data entry outputs were used for nutrient analysis. As individuals typically have similar dietary habits at breakfast time, pre-match dietary intake was only reported for the first occurring diet record only (n=18 participants), whereas match dietary intake was reported for all (n=27 cases).

The definition of “total match nutrient intake” and “total match fluid intake” includes dietary and fluid intakes from the beginning of the warm-up through to the end of match time in each case. Total nutrient intakes in energy (kJ) and grams (g) for fat, protein and carbohydrate were calculated for pre-match (n=18) and during match (n=27). Percentage energy contribution from carbohydrate, protein and fat was calculated from overall energy intake, and the mean ± SD was reported. Other nutrient analyses included pre-match fluid intake ($ml{\cdot}h^{-1}$), match CHO intake ($g{\cdot}kg{\cdot}hr^{-1}$), match fluid intake ($ml{\cdot}h^{-1}$) and match energy intake ($kJ{\cdot}h^{-1}$). Carbohydrate and fluid were compared to the recommended guidelines: ≥5-7$mL{\cdot}kg^{-1}$ of fluid consumed from one – four hours pre-event, (Thomas *et al.*, 2016), ≥1 - <2 $g{\cdot}kg^{-1}$ of CHO consumption pre-event, and 30 – 60 $g{\cdot}hr^{-1}$ of CHO consumption during the match (Burke *et al.*, 2011).

3.5.4. Body mass hydration assessment analysis.

The first morning void MSU samples were tested during the pre-match warm-up. The U_{sg} test results were categorised into the hydration cut off described earlier. Pre-match fluid and match fluid intake was assessed for volume from simple addition calculations from the fluid records from the pre-match and match food diaries. Water contains no solutes, and the underlying assumption that 1 ml is equivalent to 1 gram was applied. The weight of food and all fluids consumed at the games was obtained from the Foodworks analysis outputs, and used to determine BM mass changes.

End of match BM changes, end of match percent body mass changes, hypothetical calculated end of game BM (CalcWt2) and in-turn an estimated total sweat loss (ESL) were determined. Faecal and metabolic losses were ignored, and the following formulas were applied: [1]

- BMΔ = Wt2 - Wt1.
- %BMΔ = BMΔ / Wt1 x 100.
- CalcWt2 = Wt1 + fluid intake (ml) + food intake (gm) – UO.
- ESL = CalcWt2 - Wt2.

[1] BMΔ = end of game body mass change, % BMΔ = percentage body mass change, Wt2 = end of game weight, Wt1 = pre-match weight, CalcWt2 = the calculated end of game weight, UO = urine output, ESL = estimate sweat loss.

3.5.5. Global positioning system and time-motion analysis.

Participant and match time data from the written recorded forms were checked against copies of the official score sheets and GPS data. GPS data from the portable devices were downloaded onto GPsports software. Activity zones, using the same classification as Peterson et al (2010) were entered into the programme: walking (0-2.00$m \cdot s^{-1}$), jogging (2.01-3.50$m \cdot s^{-1}$), running (3.51-4.00$m \cdot s^{-1}$), striding (4.01-5.00$m \cdot s^{-1}$) and sprinting (≥5.00$m \cdot s^{-1}$). Movement and distance were determined within each velocity band and in total within cricketing activities of batting, wicket keeping and fielding. It was also captured for both innings, and for activity inclusive of the entire match (warm-up + both innings). Distinctions within different fielding positions and for each bowling over, independent of fielding, were not determined. The minimum and maximum bowling over running speeds were reported. Activity was almost negligible during seated times, therefore movement and distance analysis was not reported during periods of non-play when seated in the pavilion waiting to bat and during lunch.

3.5.6. Estimated energy cost.

The methodology and approach previously described and validated by Osgnach et al (2010) ultilised within the GPsports software, enabled determination of EE. The calculated MET(s) from running speed, acceleration and deceleration, and energetic cost (kJ) was analysed within selected time frames using the calculation: MET x Wt1 (where MET equals the relative metabolic load(s) output and Wt1 was the pre-match weight). The average total estimated EE (kJ) and estimated EE per hour ($kj.hr^{-1}$) range was calculated where GPS data was available over warm-up and match innings and within cricket positional activities play; batting, fielding, wicket keeping, bowling and fielding combined, pace bowling and fielding combined, and spin bowling and fielding combined.

3.6. Statistical analysis.

Statistical analysis procedures were completed using the SPSS software package (Version 24, 2017, New York). Data was normality tested using the Kolmogrov-Smimov test and visual assessment of histograms. As much of the data was non-normally distributed both mean ± SD are reported and categorical data are reported as frequencies. Independent *t*-tests were used to test differences between key variable such as match fluid intake in hot versus warm match conditions. Correlation coefficients were performed using Pearson's for parametic and Spearman's for non-parametric data to explore associations between variable of interest such as match EE versus match EI, and pre-match hydration versus end of match BM%Δ. A *P*-value of <0.05 was considered significant.

4. Results.

4.1. Study time frame overview.

The time period from the beginning of recruitment to end of data collection was nine months. Access was granted to 10 matches scheduled between November 2015 and April 2016. Six matches were 'away' games (Napier x 1, Whangarei x 2, Hamilton x 2, Cambridge x 1) and four were 'home' games (Auckland Central). Three weather-related cancelations plus a research resourcing issue resulted in final data collection from six matches (four in Auckland Central and two in Whangarei) between November 2015 and January 2016. Travel to the Whangarei games, (150 km, 2 hour drive) occurred on the same day. Five out of six matches were played to completion. Weather disruption prematurely closed game five, (the study-side were fielding in the second innings), and game one ended abruptly when all batters from the study-side were out at 34 overs during the second innings. All other games consisted of two innings completed to 50 overs.

4.2. Study participants.

The study aimed to collect ≥50 separate sets of match data from participating cricket players during phase-three. Sixty-two cricket players were available and eligible to participate. Forty-three (69%) of the 62 players consented to taking part. Five players withdrew, and 38 players completed phase-two. Further participant losses ensued beyond the researcher's control during phase-three. Reasons included weather cancelations, player scheduling of new (non-study participant) team-members, player illness, and injury. In total 42% (n=18) from initial consent proceeded to phase-three. Double and triple case representation from two and five participants respectively, resulted in twenty-seven sets of data (study cases) from 18 study participants.

4.3. Participant characteristics.

All eighteen participants were male. The ethnic majority was NZ European 61%, (n=11), followed by 17% (n=3) Indian, 11% (n=2) Māori and 11% (n=2) South African. Participant age and anthropometric characteristics for the total and from within key playing position categories are presented in table 4.1. All wicket keepers in this study were top order batsmen (1st - 3rd order) and counted as batters in table 4.1. The ages of participants ranged from 16.5 – 25.3 years. Four participants were <18 years of age at the beginning of the study with an average BMI of 20.9 kg·m^{-2} (range: 60th to 91st BMI percentile). Total body fat percentage, from DXA, ranged from 13.7 - 26.6%.

Table 4.1. Baseline participant characteristics.

Characteristics	Total n =18	Bowlers n = 9	Batters n= 9
	Means ± SD	Means ± SD	Means ± SD
Age (year.months)	18.1 ± 2.2	18.5 ± 1.8	19.3 ± 2.7
Weight (kg)	76.6 ± 7.9	74.6 ± 8.6	78.6 ± 7.1
Height (cm)	179.0 ± 6.3	177.9 ± 7.0	180.4 ± 5.6
BMI (n=14) ≥18y	24.1 ± 2.4	23.7 ± 2.6 (n=6)	24.7±1.7 (n=8)
TBF%	18.4 ± 3.6	18.2 ± 3.3	18.7 ± 4.0

BMI = body mass index, **TBF%** = total body fat percentage

4.3.1. General diet and health.

All participants (n=18) described themselves as omnivores. One participant did not eat red meat, and one participant self-reported a dairy intolerance. Eight participants reported occasional protein power supplementation usage. There were no reports of vitamin, mineral or herbal supplementation. One participant self-reported cigarette smoking.

4.4. Game characteristics.

Match time and environmental conditions for all games are presented in table 4.2. The average match time including both innings, but excluding the warm up and lunch was 343 ± 54 minutes. The average temperature and humidity across all games was 25.8 ± 3°C and 58 ± 12.5% respectively. With the exception of game five, average game temperatures were higher and humidity lower than the reported regional 30-year monthly National Institute of Water and Atmospheric Research (NIWA) averages (Appendix L).

Table 4.2. Game characteristics: Match day climate averages and innings and match times.

Game	Month Year	Region	Cases	Temperature (°C) *	Humidity (%) *	Batting inning duration (m)	Fielding inning duration (m)	Game duration = both innings (m)	Match duration = both innings + warm up (m)	Match duration + lunch (m)
1	Nov 2015	Whangarei	9	27.3 ± 1.7	49.1±6	125	185	300	360	395
2	Nov 2015	Auckland	1	23.2 ± 1.3	62.1±7	201	204	405	465	505
3	Nov 2015	Auckland	2	26.7 ± 2.8	57.5 ± 10	201	181	386	446	515
4	Nov 2015	Auckland	1	26.7 ± 3.4	65.6 ±10	183	143	326	386	418
5	Dec 2015	Auckland	9	21.3 ± 1.6	75.8 ± 7	220	75	295	355	428
6	Jan 2016	Whangarei	5	29.7 ± 1.0	50.4 ± 7	189	188	377	437	478
Total			27	25.8 ± 3.0	60.2 ±10	187 ± 33 *	161 ± 47 *	348 ± 47*	408 ± 47*	455 ± 50*

*****Means ± SD, **°C =** degrees celcius**, m** = minute

4.5. Key match playing times.

The range and mean ± SD for the times of play spent in bat (n=24), in fielding innings (n=26), across both innings (n=23) and in all cases regardless of innings played (n=27) is presented in table 4.3. Fielding data were reported minus one (n=26), due to an injury related omission from fielding (2nd innings) in game five. Batting innings time is reported less three, as there were three 12th order batsmen who did not bat. Participation across both innings occurred in 23 from 27 cases. The average game playing time was 173 ± 59 minutes (n=27). There was a wide variation of time spent within different playing positions during match time. Further case-by-case representation of playing times in key positions and in total is detailed in appendix M.

Table 4.3. Participant playing times.

Innings (data case numbers)	**Range (minutes)**	**Means ± SD (minutes)**
Batting inning duration (n=24)	3-145	32±32
Fielding innings duration (n=26)	75-204	147±50
Game duration of both innings (n=23) (fielding & batting innings)	77-281	180±58
Game duration all cases (n=27)	75-281	173±59

- Batting innings: n=24 went in to bat.
- Fielding innings: n=26, exclude (n=1) injury related omission from 2nd innings (fielding)
- Game duration of both innings: n=23, exclude (n=3) x 12th batters and (n=1) x injury related omission from 2nd innings (fielding)
- Game duration overall: n=27, including all players regardless of the number of innings played.

4.6. GPS: time-motion analysis.

GPS data were collected in 26 of the 27 cases, due to one unit not working during game one. One case of missing data were detected during download for game one, leaving 25 cases of total GPS output available for use. GPS data for batting activity resulted from 22 cases, and a combined total of 736 minutes (12.3h). GPS data from the fielding innings are reported in 24 cases from 3447 minutes (57.5h) of fielding activity. Within fielding, 1189 minutes (19.8h) of GPS data arose from fielding activity alone, 524 minutes (8.7h) from 125.2 overs of wicket keeping. There were 1734 minutes (28.9hrs) from bowling and fielding combined. Bowling activity time is not reported due to the complexity of accurately extracting this information from the GPS download. Nine pace and two spin bowlers bowled 64.5 and 12 overs respectively, totaling 76.5 overs over the six games, (mean ± SD) 7 ± 2.5. The range of overs bowled in each case varied from 2 - 10.

Table 4.4 presents the average (mean ± SD) distance per hour ($m.h^{-1}$) within five velocity band movement categories (standing/walking; jogging; running; striding; sprinting) in the activities of warm-up, batting, and within fielding innings for total fielding activity: inclusive of all fielding positions; bowling and fielding combined; pace bowling and fielding combined; spin bowling and fielding combined; and wicket keeping activity. The average total distance ($m.h^{-1}$) travelled within each activity is also shown in this table. In batting, more than half the movement (~60%) included standing and walking, and there was equal distribution of movement of 10% within jogging; striding; and sprinting categories. In fielding (n=10), 68% of time was spent in walking/standing and in the fastest velocity band more than twice the distance ($m.h^{-1}$) is covered by bowlers who also fielded (n=11) than by fielders alone (n=10), with 16.7% and 7.1% of activity in sprinting respectively. Bowlers and fielders covered similar total distances ($m.h^{-1}$) in fielding innings with a mean ± SD of 3021 ± 1084 in fielding (n=10), and 3037 ± 907 bowling and fielding combined (n=11). Pace bowlers covered more than twice the distance of spin bowlers in the high velocity sprinting band. The majority of movement for wicket keeping (95.7%) was in the first two bands, (walking/standing and jogging) and distances tapered down in the higher velocity bands with <1% of movement occurring in sprinting. The percentage of time spent sprinting was 16% in bowling, 12% in fielding innings, 10% in batting, 7% in fielding and 0.2% in wicket keeping.

The bowling intensity, time, distance and speed across velocity bands, and EE of the slowest and fastest bowling overs are recorded in table 4.5. The slowest and fastest was 12.9 $km.h^{-1}$ to 25 $km.h^{-1}$ respectively.

Table 4.4. Movement category distance by playing position across one-day cricket matches (mean±SD).

One-day cricket activity type	Number	Distance covered in metres per hour ($m.hr^{-1}$) & Distance as a percentage (%) within velocity bands					Overall Distance
		Standing/Walking 0-2·00 $m·s^{-1}$	Jogging 2·01-3·50 $m·s^{-1}$	Running 3·51-4·00 $m·s^{-1}$	Striding 4·01-5·00 $m·s^{-1}$	Sprinting ≥5·01 $m·s^{-1}$	Total $m.h^{-1}$
Warm-up	25	1231±253 68.0	448±150 24.7	56±48 3.1	60±67 3.3	17±28 0.9	1830±372
Batting	22	740±701 62.5	120±142 10.1	74±104 6.3	125±175 10.6	124±153 10.5	2072±1982
All fielding activity	24	2028±573 64.8	442±167 14.1	69±35 2.2	215±169 6.9	376±353 12.0	2753±874
Fielding	10	2027±474 68.0	506±225 17.0	73±46 2.4	165±161 5.5	211±169 7.1	3021±1084
Bowling (all) + fielding	11	2313±367 62.1	413±62 11.0	71±24 2.0	306±144 8.2	621±358 16.7	3037±907
Pace bowling + fielding	9	2333±341 60.6	401±61 10.4	78±20 2.0	338±135 8.8	702±329 18.2	3072±970
Spin bowling + fielding	2	2222±631 70.0	465±35 14.7	62±16 2.0	164±106 5.2	256±302 8.1	2883±811
Wicket keeping	4	967±60 74.5	275±188 21.2	30±21 2.3	24±12 1.8	2±2 0.2	1568±363

- Warm up: excluding 2 x GPS
- Total fielding activity (n=24) represents all fielding activity over each innings, across all playing positions: excludes 2 x missing GPS data + 1 x injured

Table 4.5. Bowling over intensity range.

Distance (m)	Standing/Walking 0-2·00	Jogging 2·01-3·50	Running 3·51-4·00	Striding 4·01-5·00	Sprinting ≥5·01	Distance (m) /over	Maximum speed reached ($km.h^{-1}$)	EE (kJ)
Slowest over (spin bowl) (N = 1)								
Distance (m) Time (s)	102.1 114	49.7 17	1.4 1	0 0	0 0	153.2 132	12.9	51
Fastest over (pace bowl) (N = 1)								
Distance Time (s)	172 150	28.6 9	11.3 2	37 7	79.2 13	328.1 181	25.1	129

4.7. Early morning pre-match hydration status.

The early morning pre-match hydration status is detailed in table 4.6. U_{sg} indicated that most players (n=22) were dehydrated (≥1.021g·ml^{-1}) and nearly one fifth, (n=5) were adequately hydrated (≤1.020g·ml^{-1}). In the very dehydrated U_{sg} category (n=2), identical measures of 1.06 g·ml^{-1} were found. The average U_{sg} (n=27) was 1.027 ± .010g·ml^{-1}.

Table 4.6. Early morning pre-match hydration status (n=27).

Early morning pre-match U_{sg} (g·ml^{-1})	**Percent (%)**	**Number**
Euhydrated (≤1.020 g·ml^{-1})	18.5	5
Dehydrated (1.021-1.030 g·ml^{-1})	74.1	20
Very dehydrated (≤1.031 g·ml^{-1})	7.4	2

U_{sg} = urine specific gravity (g·ml^{-1})

The pre-match fluid intake (consumed between post first morning void until game arrival) in the hydrated and the hypo-hydrated group was 1266 ± 1020ml (n=5) and 492 ± 249ml (n=22) respectively. There was no significant correlation between pre-match hydration status and pre-match fluid intake.

4.8. Fluid intake.

The means ± SD for total fluid (ml) intake and calculated fluid intake per hour (ml·h^{-1}) are shown in table 4.7 for pre-match, match and total fluid intake. The fluid consumption for each case is further outlined in appendix M.

Table 4.7. Fluid intake (n=27).

Time period category	**Range**		**Mean ± SD**	
	Volume (ml)	Volume per hour (ml.h^{-1})	Volume (ml)	Volume per hour (ml.h^{-1})
Pre-match	125 - 2662	35 - 1814	635 ± 551	316 ± 394
Match	570 - 3400	241-792	1840 ± 807	494 ± 182
Pre-match & match	1120 - 4887	178 - 880	2475 ± 1030	347 ± 157

- **Pre-match** = fluid intake from time waking up to start of warm up time.
- **Match** = Fluid intake from warm up time, total time fielding time, total time batting & lunch.
- **Pre-match & match** = fluid intake from waking up time, warm-up time, total time fielding, total time batting & lunch.

4.9. Sweat loss and end of match body mass change.

The ESL (total and hourly) and end of match BM changes (in grams and as a percentage) within hot and warm playing conditions are detailed in table 4.8. There were no significant differences in ESL.h^{-1} or in BM change between warm and hot match conditions (P>0.05). At the end of match time, BM change for 40.7% (n=11) of cases were positive and 59.2% (n=16) were negative. In 7.0% (n=2), a BM deficit of 2% was calculated. BM losses > 2% did not occur for any players. No significant correlation was observed between the pre-match hydration (U_{sg} ($g{\cdot}ml^{-1}$)), and end of match hydration (BM% change).

Table 4.8. Estimated sweat loss during one-day cricket matches and end of match body mass changes (mean ± SD).

Variable	**All games (n=27)**	**Warm (20-24.9°C) (n=10)**	**Hot (25.0-29.9°C) (n=17)**
Total ESL (ml)	2181±1029	1400 ± 691	2641 ± 920
ESL (ml/Hour)	553±211	464 ± 188	605 ± 212
BMΔ (g)	-204 ± 600	-10.0 ± 606	-317 ± 584
%BMΔ	-0.3 ± 0.8	-0.3 ± 0.8	-0.4 ± 0.8

ESL = estimated sweat loss, **BMΔ** = body made change in grams, **%BMΔ** = percentage body mass change.

4.8.1. Fluid intake in warm and hot match conditions.

The mean ± SD for total fluid intake in warm and hot match conditions is shown in table 4.9. Although fluid intake was higher in hot versus warm games there was no significant difference in total fluid or fluid consumption per hour between the warm and hot games (P>0.05).

Table 4.9. Match fluid intake according to temperature (mean ± SD).

Temperature	**No.**	**ml (total)**	**ml .h^{-1}**
Warm (20-24.9°C)	10	1309±529	433±122
Hot (25.0-29.9°C)	17	2152±788	493±178

°C = degrees Celsius, **h** = hour, **ml** = mililitre.

4.10. Pre-match dietary intake.

Pre-match dietary intake was mostly consumed at home with the exception of case five and seven, where 7am breakfasts were consumed at a café following an early morning cycling event. One person ate breakfast *en route* to an away game, and takeout coffees were purchased *en route*, once to a home game and once to an away game. In game one, one participant did not consume any pre match food, only 750ml of water. In two cases no fluid was consumed apart from milk added to cereal. The dietary intake pre game appears to be mostly from typical breakfast foods: cereal, toast and cooked breakfasts. No obvious trends can be seen for consumption of cooked breakfasts versus lighter breakfasts (cereal/toast) for home versus away games. In most cases pre-match dietary intake was consumed in one eating occasion. Case by case pre-match intake is detailed in appendix M.

4.10.1. Pre-match dietary intake: timing.

The warm-up start times for each match commenced at approximately 0930 or 1000 am. Timing of pre-match dietary intake is described minus one (n=26 cases), due to an atypical consumption of two breakfasts (one at 0320 am) in preparation for a cycling event in one case. Pre-match dietary intake (breakfast) occurred between 0600 and 0920 hours; before 0715 hours for away games and after 0715 hours for home games. Pre-match intake was consumed 53 – 245 minutes (0.9 – 4.1 hours) before match warm-up activity, (mean ± SD) 155 ± 59 minutes. Few reports of dietary intake were recorded from the night before (n=3).

4.10.2. Pre-match diets: food groups.

Due to high possibility of intra-person duplication of pre-match dietary routines, the pre-match dietary food group, fluids and macronutrient analysis was conducted from the first occurring diet records (n=18). Most participants (n=17) ate in the morning before arriving at matches. Table 4.10 summarises the consumption of intake from food groups. Most participants consumed grains (83%), and milk (72%). Eleven participants consumed bread/toast; five from refined white bread varieties, and six from less refined grain varieties. Breakfast cereals, low to moderate in sugar content were consumed by one third (n=6) of participants. Approximately one-third of participants ate fruit, and half consumed a main source of protein from meat, eggs or nuts. Eggs were the most common protein food consumed at breakfast, in the form of a cooked breakfast (n=6), or within a smoothie (n=1).

Table 4.10. Pre-match participant consumption per food group (n =18).

Food group	Number	Percent (%)
Grains: breads and cereals	15	83
Milk and milk products	13	72
Fruit	5	28
Meat or egg or nuts or combination Egg Meat Nuts	9 7 3 1	50 39 17 6
Sugar (sucrose) added	4	22

4.10.3. Pre-match fluid consumption.

Pre-match fluid (type) is summarised in table 4.11. Water was the most consumed pre-match drink (n=12). Milk was not consumed as a drink on its own, it was either poured over cereal, or consumed as part of a smoothie, tetra-pack milk-protein drink or a purchased expresso machine coffee. No participants reported drinking dairy milk alternatives. Three participants prepared smoothies, and the ingestion of a liquid vitamin B drink (effervescent tablet dissolved in water) was reported once. Pre-match fluid intake recommendations ($\geq$5-7mL·kg^{-1}) were met by (72.2%) of participants. The remaining 27.8% of participants (n=5) consumed <5 ml·kg^{-1} of fluid.

Table 4.11. Pre-match participant consumption from beverages (n=18).

Beverage Type	Number	Percent (%)
Plain water	12	67
Coffee	4	26
Smoothie (home made)	3	17
Milk-protein drink	3	17
Juice	1	5.5

4.10.4. Pre-match diet quantitative analysis: macronutrient intake.

The pre-match intake (g) for carbohydrate, protein and fat, was 65.6 ± 7.1, 27.6 ± 16.6 and 23.0 ± 19.8 respectively. The macronutrient percentage (%) energy (kJ) contribution in the pre-match diet was 44.9 ± 18.7 for carbohydrate, 19 ± 9.8 for protein and 30.5 ± 14.4 for fat (n=18). Participant pre-match macronutrient intake in grams and as a percentage of energy (n=18) is detailed in appendix O.

Twelve participants (66.6%) consumed pre-match carbohydrate in amounts <1 $g{\cdot}kg^{-1}$, six participants (33.3%) consumed ≥1 - <2 $g{\cdot}kg^{-1}$. No participants consumed carbohydrate in amounts greater ≧2 $g{\cdot}kg^{-1}$. The individual pre-match carbohydrate intake (n=18) is detailed in appendix P.

4.11. Match dietary intake.

4.11.1. Provision of food at matches.

Differences existed between the match venues, facilities and food and water provision. At game one, there were no facilities other than public toilets. Filled rolls from a sandwich franchise outlet were delivered for lunch. These were smaller than a regular 75g bread roll and contained meat or cheese protein fillings in small quantities. At game two, three and four there was a very basic kitchen and catered delivery of filled rolls were organised. At game two, one filled roll (round bap) and one sweet muffin was provided per player. The bread and muffin component were from highly refined products and the sandwich meat was processed. The coach requested an increase in food provision to be catered for game three and four. At game three the players were allocated a wholegrain bacon and egg sandwich, a white filled roll with meat (not processed), a highly refined sweet muffin, lamington and a banana. At game four the players were provided with two giant sized filled bread rolls, with larger quantities of meat (not processed) and fillings inside. Where fully functional kitchens were available, independent caterers provided a hot-meal, in both cases (game five and six) meat and vegetarian lasagna was on offer, as well as bread, a variety of salads (starchy, creamy, garden salad), and fresh fruit. Green beans, peas and slices of roasted ham and beef were also available at game six. Water provision varied for each game, at game one there was an inadequate supply of water bottles and these were refilled in the public toilets by the research team. Water provision improved post game one. An overview of the games, location, facilities and food and water provision is detailed in appendix Q.

4.11.2. Match snack consumption.

Dietary intake of any type surplus to lunch (including personal food snacks, nutritious fluids, sports drinks, or bananas provided by the coach) was consumed in total in 23 cases (85.5%). Extra food-snacks and or drinks brought to the game were recorded for 21 cases (77.8%). From these, 15 cases (55.6%) brought food-snacks (table 4.12), seven cases (30.0%) brought food-snacks and beverages (sports drinks / milk protein drinks), and six cases brought sports drink only. Dietary intake for each case (n=27) from warm up to the end of game is detailed in appendix R.

Extras consumed according to snack-type are detailed in table 4.12. Case consumption of more than one of the same snack-type was counted singularly. Fruit was the most common snack type, consumed in two thirds of cases; within this snack category a banana was eaten in 17 cases, and an apple in one.

Table 4.12. One-day cricket matches (including warm-up): snack type consumption (n=27).

Snack type	**Cases**	**Percent (%)**
• Fruit	18	66.7
• Carbohydrate staples: sandwich, filled roll, savoury bread, cheese & crackers	4	14.3
• Baked products: muffin, pastry, banana bread	3	9.0
• Protein based snack (tuna/baked beans/nuts)	3	9.0
• Convenience snack bars (cereal muesli or nut bar)	3	9.0
• Commercially made milk-protein drink	2	7.1
• Convenience snacks (popcorn, crisps)	2	7.1

4.11.3. Match fluid consumption.

Table 4.13 details the type of fluids consumed during one-day matches. Water was consumed in all cases (n=27). There were 12 cases of sports drink consumption (44.4%), by nine bowlers and three batters. In the cases where consumed sports drinks were obtained independently, the exact same brand type of sports drink (an electrolyte carbohydrate beverage) was consumed in all eleven cases. Tea was consumed in two cases, and two cases consumed milk drinks branded as high protein beverages with lunch. All beverage brands were identified within the dietary analysis nutrient database.

Table 4.13. One-day cricket matches (including warm-up): participant consumption from beverages/drinks (n=27).

Beverage	**Number**	**Percent (%)**
• Water	27	100
• Sports drink (electrolyte carbohydrate)	12	44.4
• Tea	2	7.4
• Milk-protein drink	2	7.4

4.11.4. Match diet quantitative analysis.

All competition nutrition (regardless of number of innings played) was assessed. There were two cases where the 12th man's game ended at the end of the first innings, however their match nutrition, including lunch was included in the nutrition analysis, as despite being the 12th man, they remained present and ready to bat in the event that it was called for. Due to injury one player was withheld from the second innings in game five. This players total match nutrition was included in the total match analysis as return to match was a possibility.

4.11.5. Match diet: macronutrient intake.

All cases (n=27) match intake (grams) for carbohydrate, protein and fat is shown in table 4.14. The total match CHO intake and calculated CHO per hour was (mean ± SD), 129 ± 50 g and 35±20 $g.h^{-1}$. The details of these per case are in appendix S.

Table 4.14. Match macronutrient intake.

N=27	CHO (g)	CHO ($g.h^{-1}$)	Protein (g)	Fat (g)
Means ± SD	129±50	35±20	49±21	36±16
Range	14 – 210 g	3 – 69	3-89	7 – 62
Median (25th-75th quartiles),	133(88-161)	33(20-46)	46(36-62)	33(25-47)

CHO = carbohydrate, **CHO ($g.h^{-1}$)** = calculated carbohydrate intake per hour, **g** = grams

4.11.6. Match & total diet: macronutrient percentage energy contribution.

CHO was the macronutrient that contributed the highest percentage of energy in most cases, n=24 (88.9%) for match, and n=23, (85.2%) for total. Thirty-seven percent (n=10) consumed < 30g of carbohydrate per hour and 63% (n=17) consumed between 30-60g of carbohydrate per hour. Individual case details are in appendix T. The representation of carbohydrate, protein and fat as a percentage of energy for match intake and for total intake is presented in table 4.15 (n=27). Macronutrient percentage contributions by case are detailed in appendix U.

Table 4.15. Macronutrient percentage contribution from match intake and from total intake.

	Match dietary intake **(%)** N=27 cases			Total dietary intake **(%)** N = 18 participants		
	CHO	Protein	Fat	CHO	Protein	Fat
Means ± SD	49.8±8.9	18.7±5.8	31.4±7.4	48.0±9.7	19.4±4.0	32.5±8.8
Median (25th-75th quartiles)	50.4 (44.3-54.4)	10.0 (15.2-22.5)	30.7 (24.9-36.3)	46.1 (40.5-54.6)	19.8 (17.4-21.6)	34.6 (22.6-38.4)

CHO = carbohydrate, **Total dietary intake(%) =** combined total of pre-match + match diet.

4.12. Energy intake.

The mean ± SD and median (25^{th} – 75^{th} percentile) for EI (kJ) within the categories pre-match, match, total (pre-match + match) and the calculated hourly match EI are presented in table 4.16. The average calculated hourly match EI ($kJ.h^{-1}$) was 1290 ± 680.

Table 4.16. Energy intake before and during one-day cricket matches.

Kilojoules (kJ) (Mean ± SD)			
Pre-match (N=18)	**Warm-up + game** (n=27)	**Pre-match + warm-up + game** (N=18)	**Match EI hour** (N=27) **(kJ.h-1)**
2516 ± 1396	4485 ± 1531	6943 ± 1757	1290±680
2354 (1407 -3917)	4694 (3445 – 5814)	7168 (6117 – 8160)	1133 (809 – 1754)

Pre-match, N=18 = assessment of first occurring pre-match diets energy intake
Warm-up + game, N = 2 = assessment energy intake for all cases from warm-up to end of match time.
Pre-match + warm-up + game, N = 18 = assessment of first occurring pre-match diets energy intake + assessment energy intake for N = 18 from warm-up to end of match time.
Match EI hour, N=27 = assessment of energy intake per hour for all cases from warm-up to end of match time.

4.13. Energy expenditure.

The mean ± SD duration, absolute distance, relative distance, EE and EE per hour within cricketing activity categories, during warm-up, game, and combined is shown in table 4.17. In the *category* game (n=21), the average distance travelled was 8805 ± 3878 metres, the total EE was 3068 ± 1411 kJ and the total calculated hourly EE was 1015 ± 266 kJ.h^{-1}. The highest hourly EE (kJ.h^{-1}) was reported in pace bowling (1289 ± 212) and the lowest reports in the activity of wicket keeping (547 ± 140). The highest reported EE in batting was 2454 kJ (1023 kJ·h^{-1}), from over 145 minutes and 65 runs between the wickets.

4.13.1. Energy expenditure and sports drink consumption.

The mean ± SD hourly EE per hour for the group that consumed sports drinks (n=12), 1939 ±196 kJ, was higher than for the group that did not (n=13), 1738 ± 114 kJ (t = .908, 23 df, P = .034). There were no significant differences in game EI or EE for participants who consumed sports drinks versus those who did not.

Table 4.17 One-day cricket: time, distance and energy expenditure within different positional activities and over a match.

Category	Mean±SD					
Activity (cases)	**Number**	**Time (min)**	**Distance (m)**	**$m.h^{-1}$** **m.min**	**EE (kJ)**	**EE/hr ($kJ.h^{-1}$)**
Batting (22)	22	33.4±32.6	1127±548	2115±665 35±11	504±548	936±312
All fielding activity (24)	24	148±65	6724±3773	2753±874 46±15	2563±1358	1053±315
Fielding	10	119±61	1682±3811	3021±1084 50±18	2280±1524	1082±283
Wicket keeping	4	131±46	3266±2988	1568±363 26±6	1141±31	547±140
Bowling + fielding	11	158±50	7863±3526	3038±908 51±15	3106±1110	1200±251
Pace bowling + fielding	9	151±53	7616±3782	3072±970 51±16	3116±1160	1289±212
Spin bowling + fielding	2	187±2	8976±2633	2883±811 48±13	3060±1248	982±391
Warm up	25	57±5	1830 ±372	1940±1864 $33±59^{-1}$	722±149	771±213
Game (both Innings)	21	181±62	8805±3878	2543±1216 52±20	3068±1411	1015±266
Match: warm-up + game	21	234±61	10616±3987	2331±840 45±14	3770±1441	938±221

Game, (both innings) n=21: 6 excludes (n=2) no GPS, (n=3) x 12th batters and (n=1) x injury related omission from 2nd innings (fielding)

4.14. Match data correlations.

No significant relationships were found between total match EE and total EI. Match EE and match fluid intake were both significantly related to ESL, *P (2-tailed)* = <0.001, (figure 1 & 2).

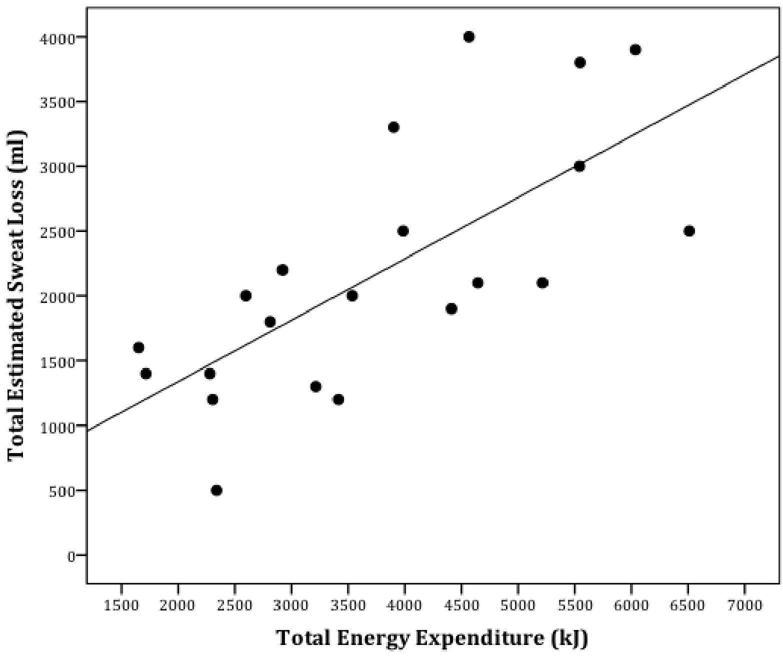


Figure 3.1. Relationship between warm-up and match total energy expenditure and total estimated sweat loss (n=21) r = .507, P<0.001

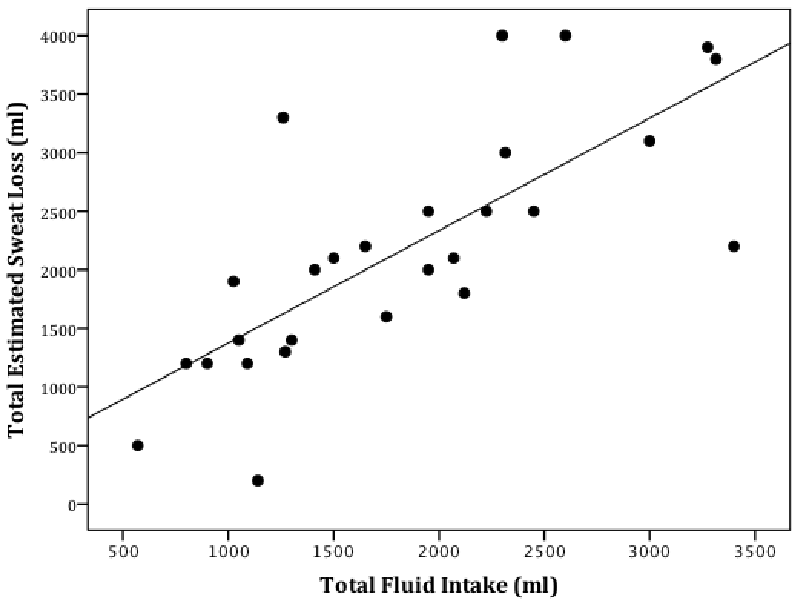


Figure 3.2. Relationship between warm-up and match total fluid intake and total estimated sweat loss (n=27) r = .555, P<.0.001

5.0 Discussion.

The aim of this observational study was to source information on the dietary and energy intake and hydration status of competitive cricket players before and during 50-over cricket games and to investigate match EE. To the best of the author's knowledge, this is the first study that has investigated all of the above during cricket matches. This study found that most (81.5%) participants were early morning pre-match dehydrated ($\geq U_{sg}$ 1.020 g·ml^{-1}), and nearly one third of participants consumed less than the recommended pre-event fluid intake of 5 - 7 ml·kg^{-1} at least four hours prior to exercise (Sawka *et al.*, 2007). End of match BM losses occurred in 59.2% of cases, but none were greater than >2%. A positive and significant relationship between fluid intake and sweat loss suggested that players were trying to replace losses. An adequate CHO intake was consumed by approximately one third of players pre-match and in approximately two-thirds of cases during the match. There was no relationship between EE and EI but there was for EE and sweat loss.

5.1. Diet, fluid and energy intake.

5.1.1. Pre-match diet, energy and macronutrient intake.

Food was eaten by 96% of participants (n = 17) before the match, and consumed within the recommended pre-event time frame of one - four hours before activity (Thomas *et al.*, 2016). Information on pre-event dietary intakes of athletes in other team sports appears negligible, however any such comparisons would not prove useful and reliable given that match start times in other sports vary over the day, and time of day might influence food selection. One-day cricket matches start in the morning. It was not surprising that the pre-match dietary intake in our study group consisted primarily of breakfast type foods such as grain products (breads and breakfast cereals) (83%) and milk and milk products (75%). Half of the participants included high protein food sources with eggs being the most popular protein food. There was an equal consumption of white versus grain variety breads, and in all cases of breakfast cereal consumption, nutrient-dense, lower in sugar (compared to other packaged breakfast cereals available) were chosen. Few participants (four from 18) included fresh fruit in their breakfasts and there was no fruit juice consumption. While the frequency of fresh fruit intake was low pre-match, we did not assess typical daily dietary intake, and so cannot draw conclusions about overall fruit intake adequacy in relation to the population guideline recommendations (New Zealand Ministry of Health, 2015). Overall, the majority of foods came from high quality animal and dairy protein sources and from wholegrain cereal sources, with a moderate frequency of refined carbohydrates.

The average pre-match energy intake (2516 kJ) was calculated for all participants from their first occurring diet records (n=18). The average ratio of energy from macronutrients was approximately 50% CHO, 20% protein and 30% fats.

The importance of CHO in pre-event diets is widely recognised (Burke *et al.*, 2011, Thomas *et al.*, 2016). One third (six from 18) participants met the lower end of the pre-exercise (1 $g{\cdot}kg^{-1}$ for >60 minutes of exercise) CHO intake recommendation (Burke *et al.*, 2011). Two-third's did not meet this recommendation, however cricket players consume a lunch and possibly extra food during match time, where athletes in other team sports cannot, therefore consideration with regards to the unique position that cricket players are in might be warranted. With more refueling opportunities during a cricket match, it is possible that players might intentionally choose to spread their dietary intake out over that time.

Rigid adherence to pre-event CHO guidelines may be more applicable to athletes participating in events of longer steady state energy expenditure, such as endurance sports, or team sports that are set in time with predictable activity patterns. Flexibility of the practical application of pre-event CHO ingestion exists within the current sporting guidelines for individuals and between sports. In our study at least four participants consumed pre-match CHO in amounts less than half of the minimum pre-match CHO recommendation. Inadequate pre-match CHO consumption on top of pre-existing inadequate daily CHO intakes can increase the risk of depleted muscle glycogen storage, and at worst can induce hypoglycaemia in athletes (Burke, 2015b). It is pertinent that cricket players are made aware of this risk and take this into consideration in the planning of their pre-match diets.

There are no specific recommendations for pre-event fat intake, other than the suggestion to consume in 'moderate' amounts, or limit fat before physical activity to minimise potential gastrointestinal issues (Burke, 2015b, Thomas *et al.*, 2016). Fat intakes are individualised in athletes when there is a requirement to match training and body composition goals. It is difficult to comment on the pre-match fat intake of the study participants, other than to state that the ratio for fat in pre-match did not appear overtly low or high at 30%.

5.1.2. Early morning pre match hydration.

Urine specific gravity tests from the first morning void were chosen to represent early morning pre-match hydration status. In this study, early morning pre-match hypo-hydration (≥1.021 g·ml^{-1}) was recorded in > 80% of cases, and the average Usg test was 1.027 g.ml-1. In a cricket study that used the same method and protocol, the average Usg in high performance female cricket players was 1.022 g.ml-1 (Soo and Naughton, 2007); similar to this study, the average was indicative of early morning pre-match dehydration, although to a lesser extent. The ratio of pre-event hydrated versus hypo-hydrated was not described (Soo and Naughton, 2007). In another cricket study, U_{osm} hydration testing on 20 first-grade male cricketers (aged 19 -22 years) took place at 11 am immediately before the match (Gore *et al.*, 1993); the different hydration biomarker and time of testing not allow comparisons to these study results. Due to the limited published literature on pre-match hydration in cricketers players, the typicality of the results from this study in the overall competitive male cricket player population is not possible

In other team sports where pre-event hydration status of athletes via U_{sg} testing has occurred, the results are somewhat mixed. High incidences (>50%) of pre-event hypo-hydration have been reported in professional basketball players (Osterberg *et al.*, 2009) and elite soccer players, (Voitkevica *et al.*, 2014). Moderate levels of pre-event hypo-hydration have been reported in professional soccer players (Aragon-Vargas *et al.*, 2009) and in club and university mixed sports athletes (Magee *et al.*, 2017). As in each of these studies the urine samples were taken just prior to the sporting event, it was likely that participants had eaten. Urine concentration biomarkers, (U_{sg} or U_{osm}) are easily influenced by food and fluid, and thus elevated concentrations can result even in the absence of body water loss (Cheuvront *et al.*, 2015), thereby decreasing the reliability of the results.

5.1.3. Pre-match fluid intake

In our study, pre-match fluid consumption occurred in 100% of cases and the average intake was 635 ml. Twelve participants (67%) consumed plain water, and an equal number of participants consumed other beverage types. Definitive pre-event fluid intake recommendations for cricket do not exist, however sporting authorities recommend commencement of exercise in a euhydrated state and to drink approximately 5 - 7 $mL{\cdot}kg^{-1}$ (in total) up to four hours before exercise (Sawka *et al.*, 2007). In total, close to two thirds of cases consumed pre-match fluid in amounts between 5 $mL{\cdot}kg^{-1}$ and 7 $mL{\cdot}kg$, and the remaining third consumed < 5 $mL{\cdot}kg^{-1}$. The average pre-match fluid intake per hour was little more than a standard cup (316 $ml.h^{-1}$) and the total fluid intake varied from 125 ml to >2500ml.

As incidences of dehydration (via U_{sg} testing of the first morning void) and pre-match fluid intakes less than recommended occurred, the average pre-match fluid intake in dehydrated versus euhydrated were calculated. The average pre-match fluid intake was more than double in the euhydrated group, (1266 ml) versus the dehydrated group, (492ml).

It is not known if pre-match fluid intake was strategically planned or consumed in response to thirst. Contributing factors to the incidences of lower than recommended fluid intakes can not be known without further investigation but may include the following: that cricket players are relaxed around pre-match fluid intake due to match time drinking opportunities, that cricket players are hesitant to pre-hydrate to in an effort to minimise match-time bathroom visits or that pre-event hydration guideline knowledge deficits exist.

5.1.4. Pre-match diet intake summary.

This is the first study to report on pre-match dietary intake of competitive 50-over cricket players. The absence of pre-match dietary data in the literature does not permit conclusions to be drawn from this study about the typical pre-match diet of competitive cricket players. The competitive cricket players in this study ate mostly from nutritious breakfast food sources, across all food and macronutrient groups and within reasonable pre-event time frames.

Pre-match nutrient and fluid guidelines are designed to support performance and nutritional health. Individual pre-match dietary plans should be determined within the context of an individual's overall daily energy and nutrient requirements alongside consideration of fuel demand predictions according to the activity of their sport or playing position. The results from this study indicate a need to monitor pre-match dietary intake in this group of cricket players. Monitoring could serve as a screening tool to help identify those requiring education and support around meeting minimum recommended energy, CHO, and fluid intakes.

While pre-hydrating to the level that is recommended in endurance athletes might not be necessary in cricket players, the unpredictable nature of cricket matches presents challenges in developing pre-match hydration strategies. Our results indicate that it would be valuable to educate this group of cricket players on basic home hydration assessment and corresponding fluid plans to support day-to-day euhydration.

5.2. Match-diet.

Food choice and quantities were influenced and limited by the foods that were available. Match lunch comparisons in competitive cricket or other team sports are not possible due an absence of information. With the exception of tournaments, no other team sports break at half time for lunch, and this may explain the gap in the literature. Lunch-time dietary intake was analysed in all 27 cases regardless of innings played. In our study two 12th men and one bowler's game ended at the end of the first innings. There was a chance that the 12th men could have been called on to bat, and that the injured bowler may have returned to the field. The assumption made was that players were eating knowing that the possibility of return to play existed, and thus the inclusion of lunch diet data for these cases. These scenarios highlight the challenge that cricket players might have in predicting their match energy requirements for the afternoon.

5.2.1. Match dietary provision.

Lunch catering varied between fixtures, and as a result food type, nutrients and quantity were inconsistent between matches. The host team coach arranged the catering. Budget and availability of food providers may be factors that influence catering provision at competitive cricket matches. It was unknown if the coaches inquired about players' dietary preferences. For example, at the first match, an equal provision of vegetarian and non-vegetarian franchise filled rolls were provided, and yet none of the participants identified as vegetarian. It was also unknown if caterers had the capacity to supply special diets if requested. As the catering at matches affects dietary intake, suggestions for the future might include to investigate the process involved in the final decision making by the coaches and team management for catering at the games.

5.2.2 Match dietary intake.

In all 27 cases lunch was consumed and one participant chose to bring lunch independently. The average match macronutrient intake as a percentage of energy for CHO, protein and fat were almost identical as for pre-match.

Fifty-over cricket is played over many hours, and predictably, the consumption of a snack or snacks occurred most cases (85%). Banana was the most popular food snack consumed, possibly due to being provided at some of the games. Fresh fruit was brought to the game independently in only one third of cases. All the remaining food snacks consumed (in 17 cases) came from convenience processed packaged foods. The convenience foods were generally protein and CHO based.

Carbohydrate was a key match nutrient of interest because of its role in increasing exercise capacity, activity performance, and the potential to enhance the skills component in team sports (Jeukendrup, 2014). The exercise CHO guidelines suggest an intake of 30 – 60 g per hour in start / stop sporting events (Burke *et al.*, 2011). The practical application of these guidelines allow for a downward adjustment in circumstances of lower exercise intensity (Jeukendrup, 2014). The average calculated CHO intake in this study was approximately 35 grams per hour. Carbohydrate was consumed within the recommended range (30 - 60g per hour) in almost two thirds of cases (63%), and in amounts lower that the recommendation (< 30g CHO per hour) in more than one-third (37%). These results indicate a need to educate some of the study cricket players the importance of adequate CHO match ingestion.

Guidelines for fat intake during team sports are vague as generally these are individually determined. Sporting authorities report that a daily fat intake <20% of total energy is detrimental to sporting performance and health (Thomas *et al.*, 2016). Our results are not reflective of total daily fat intake, but revealed an adequate (not deficient) ratio of fat consumption (31% of total match energy) at the match.

Sports drinks provide a convenient quickly absorbed fuel and fluid source for athletes (Burke *et al.*, 2011). It was not surprising that in almost half of the cases CHO electrolyte sports drinks were consumed throughout the game. Sports drinks are recommended for use over longer durations (45 – 75 minutes) of sustained high–intensity exercise (Burke *et al.*, 2011). The majority of sports drink consumption was observed in the bowlers, and in three cases of high scoring batsmen. Gathering information on sports drinks consumption relative to time and activity would have provided more information on the description of sports drink supplementation practices at matches. High intensity movement patterns and large distance are documented for bowling activity (Petersen *et al.*, 2010); it may be that bowlers anticipate higher sweat rate and refueling needs and look to sports drinks to support their performance. Conducting player interviews or questionnaires regarding sports drink consumption, might be useful in future studies to clarify player justifications and reasoning of match sports drink consumption.

5.2.3. Match dietary intake summary.

This study was unable to detail exact timing of match food and fluid intake in relation to time and activity, however from observation it appeared that the majority of food consumption took place during lunchtime. A key study finding was the inadequate ingestion of match CHO in 37% of cases. There are recommendations in the sporting literature that suggest a need for further investigations on CHO ingestion and its effect on physical and skills performance in intermittent team sports (Jeukendrup, 2014).

The effect of low CHO intake on cricket performance has not been investigated before and might be warranted for the future.

5.2.4. Match fluid intake.

In this study the average match fluid intake for all cases (n=27) regardless of whether one or two innings was played was close to 2000 ml. The calculated average match fluid intake was 494 $ml \cdot h^{-1}$ and there were no significant differences in fluid intake between the warm (433 $ml \cdot h^{-1}$) and hot (493 $ml \cdot h^{-1}$) playing conditions. Only two other studies have reported on the *ab libitum* fluid intake during cricket. Gore et al (1993) investigated the fluid intake across three different temperature conditions. The calculated hourly average fluid intake was not reported; when calculated was 525 $ml.h^{-1}$ from bowlers performing in hot conditions. This was only slightly higher than the average fluid intake in this study. The mean hourly fluid intake of high performance female cricket players from six innings in another study ranged from 150ml to 320ml per hour; calculated average, 250ml per hour. The average hourly fluid intake of the female cricket players was almost half of the mean hourly fluid intake reported in our study. Lower total body water composition of females (Oppliger and Bartok, 2002) and lower sweat rates in females (Sawka *et al.*, 2007) may have explained this.

Guidelines that quantify definitive recommendations for fluid intake during team sports events do not exist. The current guidelines emphasize the importance of starting an event hydrated and recommend adequate fluid consumption during an event to prevent excessive dehydration (Sawka *et al.*, 2007). This study interpreted the adequacy of match fluid intake from end of match hydration status and from assessing the relationship between fluid intake and estimated sweat loss. Less than half of the cases ended the game in positive body mass (44%), which suggested that there was a fluid intake deficit throughout the match in more than half of the cases. However a detailed look into the BM% losses that actually occurred showed that no serious BM% losses (> 2%) existed. In addition to this, the strong association between match fluid intake and ESL that was found might indicate that most of the cricket players replenished fluid intake close to their fluid losses (sweating). Never the less, the results do suggest that improvements in match fluid replenishment for approximately half of the cases were warranted.

5.3. Body mass change

5.3.1. End of game hydration status.

Sports performance can be compromised during activity when BM loss > 2% from body water fluid deficits and electrolyte changes occurs (Sawka *et al.*, 2007). A recent publication that reviewed fluid balance in team sports reported that BM losses greater than two percent are reported consistently in soccer, and milder BM losses have occurred in other sports, such as American football, rugby and basketball (Nuccio *et al.*, 2017). The mean BM percent change in our study for all cases, – 0.3% (n=27) and -0.4% (n=17) in hot temperatures (25.0 – 29.9 °C), appeared to be lower than results found in other studies of cricket players.

When Gore et al (1993) conducted a hydration study on high performance male cricketers they reported BM% losses of 4.3% in hot conditions (27.1°C). It is pertinent to note that the results in Gore et al (1993) arose from just three bowlers. Aside from the high temperature conditions, likely to induce increased sweating, other factors pertinent to bowlers might possibly explain the high BM% losses in that study. For example the work rate of fast bowlers across all cricket formats has been shown to be higher than the other playing positions (Petersen *et al.*, 2010). Increased work-rate coupled with high temperatures and fewer opportunities to drink (as was described in the study) may have put those particular fast bowlers at higher risk of excessive dehydration. Another hydration study in high performance female cricket players during tournament games, reported on BM% changes occurring from the beginning to the end of the each innings, but not on the total BM% changes from the beginning to end of match. However similar to us they found both negative and positive BM% changes existed, and these ranged from -0.56 - +0.11% (Soo and Naughton, 2007).

Despite the high occurrence of cases (>80%) testing dehydrated for early morning pre-match, and the warm to hot playing conditions that prevailed, BM losses > 2% did not result. The highest BM% losses reported for this study were equal to 2% (n=2). Individual data for these cases showed that one case was dehydrated pre-match and the other was not. Both players consumed ~ 500ml fluid per hour and had lengthy batting durations, equaling to 232 and 281 minutes. One had the highest calculated total game EE (5907 kJ) and the other had zero urine output. A limitation of this study was that the over all study numbers did not permit robust statistical testing to determine if associations between the variables of interest (as described above) and BM loss exist.

The major factors influencing acute BM changes over the duration of a one-day cricket match would be related to amount of food and fluid taken in (consumed) versus total fluid and faecal matter lost. As reliable and accurate assessments for faecal losses were not possible for this study and metabolic fluid losses were unaccounted for, individual BM changes for some cases may have been slightly under-estimated. Withstanding these limitations, there did appear to be no severe cases BM% loss in this study. However, in an effort to minimise any risk of serious dehydration in the future, individual hydration monitoring practices and the development of individualised fluid and rehydration plans should be considered. It is specifically recommended that this practice occurs in athletes that experience BM losses of 1 – 2% (Maughan and Shirreffs, 2008).

5.3.2. Estimated sweat loss.

In this study the average total estimated sweat loss was 553 $ml{\cdot}h^{-1}$ and the average fluid intake per hour was 494 $ml{\cdot}h^{-1}$. The ESL calculation (end of match weight less the calculated pre-match weight of food and fluid, minus urine) gave a crude result. For example weighing the food would have improved the accuracy. Because of this crude estimate, reporting with certainty the degree to which fluid loss was actually replaced is difficult. However the positive association between match fluid intake and estimated sweat loss (described earlier) coupled with the modest end of match hydration results (also described earlier), might support the view that this particular group of cricket players attempted to replace fluid from sweat loss relatively well.

In other team sports, higher sweat and BM% losses with similar fluid intakes have been reported. For example, the calculated, hourly mean sweat loss, fluid intake and BM% loss from twenty-two 18-24 year old competitive male football players over a 96 minute football match played in cool conditions was 1050 ml, 540 ml, and 1.1% respectively (Maughan *et al.*, 2007). Football is a physically demanding game with reports of higher EE (Maughan *et al.*, 2007). A contributing factor to the higher sweat rates reported in the football study, might have been attributed to this. In study of professional male basketball players where excessive sweat and BM% losses were recorded over short durations of play (21 – 40 minutes), the high intensity workload and limited opportunities to drink were the factors named by the authors as the likely cause (Osterberg *et al.*, 2009). When reviewing sweat rates cause in athletes, it is pertinent to consider factors during activity other than work rate and environmental temperature that can affect sweat rate, for example , body size, gender and individual sweat rate variation (Sawka *et al.*, 2007). While sweat rates in cricket less than (Soo and Naughton, 2007) similar to (Gore *et al.*, 1993) and greater than the results in this study have been reported (Gore *et al.*, 1993), further investigations would be essential to determine typical sweat rates in competitive cricket players and in comparison to other sports.

Cricket players might struggle to replace water and electrolyte losses during high work rate periods during a match. Sweat sodium losses were not determined in this study. Absorbent patch testing is the only way to determine individual sweat sodium loss on the field (Maughan and Shirreffs, 2010) and sweat electrolyte losses need to be replaced to restore euhydration (Sawka *et al.*, 2007). A recommendation for cricket players that experience losses BM losses between one and two percent, might include to conduct sweat testing on the field in addition to hydration monitoring in cricket players. This practice can determine individual sweat rates and be useful for the development of individual fluid and electrolyte replacement plans.

5.4. Energy expenditure.

The overall demands of cricket are not clearly defined, one of the ways to investigate sporting demands is via assessment of the energy cost. GPS with a built in accelerometer was the most reliable, practical, inexpensive and accurate method of choice. Units do not affect player performance and provide immediate (once downloaded) TMA feedback. Advancements in the development of GPS have enabled efficient TMA monitoring in team sports, however as with any technological reliance, there are data loss risks involved; in GPS this might include unit malfunction or software download issues, both of which occurred in our study.

The physiological demand in team sports is often described and compared via workload assessment from TMA. In this study we estimated match EE from match GPS TMA data. The GPS units used included software that enabled calculation of EE from metabolic outputs derived from a validated formulae (Osgnach *et al.*, 2010) integrated into the GPS software. This formulae was developed by Osgnach et al (2010) from an earlier investigation by di Prampo et al (2005) which proposed that metabolic demands differ at the same running speeds due to differing acceleration and deceleration. To the author's best knowledge, no other formulae that considers the energy cost of acceleration and deceleration has been developed. A clear description of the limitations to their methods can be found in their discussion (Osgnach *et al.*, 2010). We believe that assuming the limitations are understood and accepted, estimating exercise EE from GPS data output could be applied in this study by using Osgnach et al (2010) method.

This is the first investigation to assess EE of cricket players during a cricket match since 1955 (Fletcher, 1955), and although two other studies have assessed EE in cricketers since, both have taken place in experimental design simulated conditions of batting (Christie *et al.*, 2008, Pote and Christie, 2014). An attempt to make comparisons will be made with the recognition that the participants, study group and methodologies used differed across each study.

Fletcher et al (1955) estimated the EE in test cricket via indirect calorimetry pre-determined energy costs from batting and bowling. The energy cost in training sessions in the nets, was calculated to be higher than that of the games (Fletcher, 1955). After computing a theoretical EE of an "average test player" from an average of 100 hours of test-match play, he proposed that the EE in a test-match game was approximately 650 $kJ{\cdot}h^{-1}$, much lower than our study one-day match average, which was 1015 $kJ{\cdot}h^{-1}$. The average hourly EE that we determined in batting and fielding activity was also higher, but we did not have the average EE of bowling activity in isolation from fielding to compare.

There are various explanations for the different average EE reported between the studies, and the different study design and methodologies used and technology available cannot be ignored. For example, the 1955 study categorised all running activity into 7.5 mph and all walking activity into 4 mph, whereas our activity zones were determined in narrower categories and with higher accuracy. Furthermore, given that the physical demands on todays competitive cricket player have increased, (Noakes and Durandt, 2000), comparing the results from this study of one-day cricket players to that of a 'hypothetical' typical test cricketer from half a century ago does not permit conclusions to be drawn about the typical energy expenditure in cricket today. The current study results do however allow some challenging of the historical viewpoint by Fletcher et al (1955), that the energy cost of cricket is the same as that of walking.

The Christie et al (2008) and Pote et al (2014) investigations were similar in design protocol, participant group, participant numbers and energy cost methodology. Both used a portable metabolic indirect calorimetry system ($k4b^2$) and had participants simulate batting. Participants ran 28 shuttles (14 double shuttle runs) in the 2008 study and 42 single shuttle runs in the 2014 study. The average energy expenditures reported were 2536 $kJ{\cdot}h^{-1}$ (Christie *et al.*, 2008) and 2776 $kJ{\cdot}h^{-1}$ (Pote and Christie, 2014). The average energy cost of batting activity (n=22) in our study was much less and calculated at 936 $kJ{\cdot}h^{-1}$. In our study, even the highest batting EE case (1023 $kJ{\cdot}h^{-1}$), which entailed 145 minutes batting and running between the wickets 65 times, was less than half the energy cost reported in the simulation studies.

The batting EE differences might be explained by the different energy cost analysis methodologies and study design differences. The batting EE in this study was estimated from actual games. Batting EE can be partially dependent on the game plans; for example match power plays might have influenced EE. The power plays scheduled in this study were not investigated. Considering power plays have been known to influence runs, (Silva *et al.*, 2015) it may have been insightful to have analysed the EE during these imposed periods. Batting entails short bursts of high intensity running, and the underestimation of this type of activity has been reported for GPS (Vickery *et al.*, 2014a). Thus it is possible that batting EE in this study was underestimated.

This study was observational, running between the wickets would have occurred as needed, and strategically with the aim of conserving energy. Where as in the experimental design simulation studies, the participants had to run, and may have been expected to run as fast as possible. In addition to this, in our study only three from 22 cases actually batted >60 minutes, therefore the batting $kJ \cdot h^{-1}$ calculations in our study were projected in all other cases, thereby assuming consistent EE over an hour.

This study did not find a relationship between match EE and match energy intake (n=21), but did find a significant relationship between match EE and estimated sweat loss (n = 21). Multiple factors (as described earlier) can contribute to sweating during activity and this association alone does not impart causation.

5.4.1. Energy expenditure summary.

In the sport of cricket, a varied energy cost might be predicted to occur between different playing positions, different game formats, and between different matches within same individuals. As the first research group to investigate EE during 50-over cricket matches, the results cannot be extrapolated across to all competitive males in 50-over cricket games. Nonetheless they do permit the previously held beliefs that cricket is as low in energy as that of walking, to be questioned. The findings from the results in this study might be used as a starting platform towards beginning to understand the demands of the game, at least from an energy perspective and encourage further research for future developments in the game.

Cricket training sessions can be demanding; and this was reported back in 1955, when it was found that the training sessions required a larger energy cost than the game (Fletcher, 1955). Periodising dietary intake around training has been reported to provide optimal training benefits in athletes (Burke, 2015a). To the best of the authors knowledge the EE of cricket specific training sessions has not been investigated since 1955. As training is so vital to match performance, there may a benefit from investigating the EE and dietary intake around the training strength sessions.

5.6. One-day cricket match movement characteristics.

The time motion analysis data of competitive males cricket players during one-day cricket matches in this study appear similar to those from an elite group of competitive male cricket players (Petersen *et al.*, 2010). The results from Peterson et al (2010) are replicated in Table 5.1 (appendix V) and show the GPS TMA from Australian cricketers in 50-over cricket matches. From direct comparison observations it appeared that the male cricket players from this study had similar movement patterns. The five activity zones referred to are walking (0-2.00$m \cdot s^{-1}$), jogging (2.01-3.50$m \cdot s^{-1}$), running (3.51-4.00$m \cdot s^{-1}$), striding (4.01-5.00$m \cdot s^{-1}$) and sprinting (≥5.00$m \cdot s^{-1}$). The distances covered within the first three activity zones were similar for fielding activity, however the data from our fielding show larger distances were covered in sprinting than striding. In the study of Peterson et al (2010) cricketers covered larger distances in wicket keeping than ours, but overall the trend observed was much the same, with most movement in the slowest zone, and distances tapering down into the higher velocity activity zones. Similar to Peterson et al (2010), we did not quantify bowling in isolation. In spin and pace bowlers, similar distance coverage trends in walking/standing and jogging were observed. While both studies showed that pace bowlers covered more distance than spin bowlers in the higher velocity striding and sprinting movement categories, the current study only obtained results from n = 2. While these similarities occurred, the participant numbers in this study were fewer in total and within positions. In addition to this, the competitive level in Peterson et al (2010) was higher than the participants in the current study. Therefore the movement patterns results cannot be reported as fully representative. Further data from future studies in comparable study participant groups is required to define positional movement patterns in competitive one-day cricket players.

5.7. Study strengths and limitations.

5.7.1. Study design and data collection.

A foremost design strength of this observational study was the research team presence at the games. The physical presence of research assistants facilitated capture of accurate data at the games. This occurred from observation, recording and data collection in real time, thus not relying on retrospective data. For example, this allowed the research team to check pre-match diet records on arrival for accuracy, to photograph food alongside documentation and to remind water runners of the water provision protocol at each game. It enabled further accuracy during the analysis phase, for example, cross checking and validating hand written time movement records to the GPS software outputs when selecting time periods for analysis.

Conversely the presence of the research team may have directly altered the behaviour of the participants in relation to dietary intake at the games. Altered dietary behaviour in study participants is a known limitation in prospective dietary collection methodology (Deakin *et al.*, 2015). The study participants knew of the nutrition knowledge backgrounds of the research team, and may have felt a need to impress, and change food choices and amounts consumed from usual. In addition to this, the research team may have altered what would have been the natural course of fluid intake during the first game when they offered to refill water bottles due to poor facilities water provision. Had the research team not intervened, the total fluid intake and end of game hydration status may have been different.

Weaknesses of observational study designs are the inability to control for confounders or unexpected circumstances that affect study results (Boyko, 2013). For example, the early morning cycle event in which two participants took part in before the first game was not anticipated and may have skewed the pre-match dietary intake results.

The development of a research match protocol guideline that organised each research assistant to observational and data collection tasks was a planning strength of this study. However not all circumstances that might occur on the field could have been controlled for and flexibility in the data collection process was required. For example, in the second innings of the first game, batters from our study went out in swift succession. This situation was challenging as it pressurised the research team to work fast whilst still maintaining that end of match study protocol were adhered to by the participants.

5.7.2. Participants.

It has been recognised that competitive athletes have busy lifestyles, (Burke, 1995) and as expected some drop out related to this transpired. A 12% dropout rate between phase-one (initial consent) and phase-two transpired, the cricketers reported that they were too busy with other (sport and work) commitments. The total participant study number (n=18) confirmed at the end of phase three data collection was 42% from initial consent. This occurred due to reasons outside of the researchers control. Cricket pitch preservation is one of the determinants of game and performance and player safety (Lemmer, 2012), and weather is one of the main factors affecting cricket pitch condition. This study encountered multiple match cancellations due to weather that were a major limitation in data collection. Similarly, weather has affected other cricket research studies. After a lengthy duration waiting on specific temperature conditions, Gore et al (1993) resorted to adopting a simulation protocol for study completion, and in another study weather-related cancellations affected final study numbers (Soo and Naughton, 2007). In addition to weather, the study aim to collect ≥50 phase-three data cases was unmet because of limited access to high competition level games, player selection, sickness, and injury. Conversely, participant co-operation and study protocol compliance was a particular strength of this study, and as a result, data that were lost to the study were not as a result of participant non-compliance or error. While the overall reduced participant numbers were a statistical analysis limitation, the study design fortunately permitted player participant observation across multiple cricket games.

*5.7.3. Participant characteristics***.**

The mean height value in this study, 179 ± 6.3 m was comparable to average heights reported within other high performance male cricketers, ranging from 180 – 188 m (Johnstone and Ford, 2010, Lees *et al.*, 2016, Micklesfield *et al.*, 2012, Stretch, 1987, Stretch, 1991, Stuelcken *et al.*, 2007). The height trend noted in the literature tends to favour bowlers as being taller than batters (Johnstone and Ford, 2010, Johnstone *et al.*, 2014, Stretch, 1991), however this was not observed within this study population, mean ± SD height in bowlers was 177.9 ± 7.0cm compared to 180.4 ± 5.6cm in batters. The participants in this study were younger (18.1 ± 2.2yr), compared to the studies formerly cited (Johnstone and Ford, 2010, Johnstone *et al.*, 2014, Stretch, 1991), and thus some of the study participants may have not met their growth height potential.

BMI was reported for those ≥18 years (n=14), and resulted in a mean ± SD of 24.1 ± 2.4 kg·m^2. Comparable mean BMI values of high performance male cricketers have been reported by Johnston et al (2010) and in two recent anthropometric studies on fast bowlers (Lees *et al.*, 2016, Micklesfield *et al.*, 2012).

To the best of the authors' knowledge, this is the only study that has reported on total DXA body fat percentage in high performance cricket players across all playing positions. The mean body fat percentage value was 18.4±3.6% for all (n=18), and 18.2 ± 3.3% in bowlers (n=9). In the current study body fat percentage for bowlers were higher than those reported in high performance bowlers in two other DXA studies (Micklesfield *et al.*, 2012, Lees *et al.*, 2016). The differing level of cricketing performance between this current study and those fore-mentioned may explain this.

While the male competitive cricket players in this study appeared anthropometrically similar for BMI and height to competitive and high performance male cricketers reported elsewhere within the literature, the results are generalizable across all competitive 'one-day format' male cricket players. Further in-depth, larger scale, anthropometric investigations in competitive cricket players, (male and female), from different game formats would be required to determine the anthropometric profile of competitive cricket players.

5.7.4. Diet assessment.

In this study the main strength of the match time dietary assessment method was the observational design. However limitations are inherent in all methods of dietary collection and analytical procedures (Deakin *et al.*, 2015), and one that may have existed with this method included the possibility that some participants altered their food intake in response to having their dietary intake directly observed and monitored. To minimise pre-match diet recording error as far as possible, the lead researcher instructed participants on how to complete food records prior to phase-three. While weighed diet records have been reported to be the most accurate diet assessment method, this method was not progressed at the matches in our study due to the potential participant burden and possible delay to fuel replenishment and was a major limitation in the diet and weight analysis component of this study.

The importance of timing of fluid and nutrient ingestion is well documented in the sporting literature to be a key factor in sports performance nutrition (Thomas *et al.*, 2016). This study quantified nutrient and energy intake and described foods and fluid consumption. Because of the extensive data collection protocol it was not possible to describe exactly when eating and drinking always occurred and was a limitation to describing the nutrient and fluid intake in relation to activity, intensity and physical demands.

Post-match recovery nutrition and fluid intake was not investigated during this study. Post-event nutrition guidelines for athletes do exist, (Thomas *et al.*, 2016) and there are guidelines pertaining specifically to carbohydrate intake after exhaustive exercise (Burke *et al.*, 2004). Post exercise nutrition is a key component of recovery in high performance athletes times (Burke *et al.*, 2004). Not investing the post match nutrition was a limitation to reporting on the overall adequacy of the cricket players' event nutrition practices for this study.

5.7.5. Hydration and body mass assessment.

Sporting research authorities have recommended to assess athlete hydration status via on-waking U_{sg} and to assess end of match hydration from BM percentage change (Sawka *et al.*, 2007). The pre-match and post-match hydration assessment methodologies that this study utilised were considered the most reliable and practical to use within this study setting, but the methodology and reporting of these were not without limitations.

For example, the pre-match hydration that this study reported on was taken from the U_{sg} of the first morning void; participants did eat and drink after this and before the match. The study chose to sample U_{sg} at this time because U_{sg} is more accurate when assessed following a period of stable hydration (Sawka *et al.*, 2007, Cheuvront *et al.*, 2015). However early morning samples cannot accurately describe hydration status immediately before the match, and conversely, collection of urine samples for U_{sg} testing just before the match would have produced confounding results. This is because urine concentrations measures are influenced by food, fluid and sweat (Cheuvront *et al.*, 2015). The study managed this issue by referring to this hydration marker as the 'early morning' pre-event hydration status. In reality the single morning measures that this study took, were just one snap shot of early morning pre-event hydration status and repeated early morning U_{sg} tests inform more so about day to day body water balance (Cheuvront *et al.*, 2015).

In addition to this, the body mass losses that this study calculated could have been slightly underestimated due to metabolic and faecal losses that were ignored. While it is almost impossible to accurately account for these losses in a non-laboratory environment, certain assumptions can be made and standard metabolic losses can be factored into sweat loss equations. This study did not factor this in because the application of this in our study group was likely to introduce error given that the activity profile is so varied in cricket. In other research hydration studies, faecal loss has been factored in from taking BM measurements before and after all bathrooms visits (Gore *et al.*, 1993, Soo and Naughton, 2007). This study did not adopt this protocol due do to the potential subject burden and game interference.

Blood samples that test for plasma osmolality, taken immediately before and after the matches would have more accurately described the pre-match and post-match hydration status of the cricketers in this study. Unfortunately this method is complex (requires a skilled phlebotomist), time consuming and expensive. Further this this, it may have caused undue stress to participants and their game, and therefore was not an option.

5.7.6. Global positioning system.

Choosing GPS methodology made it possible for the study to adopt the exact same movement category velocity bands for TMA analysis as described in Petersen et al (2010) to enable direct comparisons. In addition GPS was considered the most practical and reliable method to estimate EE. Metabolic power calculation derived energy costs were made possible from the GPS application in this study, but not without limitations. While the GPS model used in this study has been shown to have acceptable validity and reliability for use in cricket, it has also been found to be less valid and reliable in its assessment in the shorter distance sprinting velocity (Petersen *et al.*, 2009a). Further to this the literature suggests that GPS outputs can overestimate EE in walking (Hull, 2018) and GPS does not capture rapid directional change well (Rawstorn *et al.*, 2014). For example, the energy expenditure from turning at the wickets during runs, or from crouching and sudden movement in wicket keeping may not have been accounted for via GPS. These limitations around the reliability of GPS in estimating EE are understood as a major limitation in the GPS derived EE results of this study.

In sports, a widely accepted limitation of GPS use, are that units do not work indoors and this limitation would need to be considered when GPS is used in studies where TMA of activity is to be measured indoors. This did not affect the current study as all activity was outdoors, during lunch-time the players were sedentary, and we accounted for this by not including lunch-time data.

5.8. Main findings and conclusions.

The average percentage of energy contributions from nutrients followed the same trend (~50.0% carbohydrate, ~20.0% protein and ~30.0 % fat) for pre-match and match diet. While pre-match dietary intake was found to be from high quality food sources, two thirds of the participants consumed an inadequate intake of pre-match CHO and approximately one-third did not meet the lower end recommended pre-event fluid in intake of 5 – 7 $mL{\cdot}kg^{-1}$. Furthermore, during the match, more than one third of cases did not meet the minimum recommended CHO intake 30g per hour. Sports drink consumption during the match was reported in 44.4% of cases. We could not draw conclusions regarding the appropriateness of the sports drink consumption in our study, but we did discover that it that existed mostly within bowlers. Higher energy costs were not evident in all cases of bowling and hence there may have been some over consumption of sports drink within this study group.

Without further investigations of pre-match and match dietary intakes in cricket players, we cannot extrapolate the study recommendations across all competitive cricketing populations. In addition to this, the assessment was conducted in a country that typically eats a western type diet, and this was the style of food was consumed pre-match and observed at the cricket games. The dietary findings from this study might differ if replicated in other countries where cricket is played, due in part to cultural and environmental factors. Never the less, these findings highlight the necessity of monitoring pre-match and match dietary and fluid intake. Monitoring could serve to screen and identify those with any nutritional issues and help target nutritional education and planning where it is needed.

The moderate BM% losses reported in this study, coupled with the significant positive relationship between match sweat loss and fluid intake that were found, indicated that many of the study participants were close to, and some were effective in, replacing body fluid lost during the match. While serious body fluid losses did not occur for this group, the results did vary. Therefore implementing practices that minimise the risk of serious dehydration occurring is still warranted. Prioritising education on hydration monitoring and rehydration practices for this group of competitive cricket players is recommended.

Match dietary intake was largely determined by the food supply provided, however cricket players did have the option of bringing their own food. There was no consistency in the quality or nutrients provided between the games, and in some cases there was insufficient food. The average intake from fat during the match was >30%, which may have suggested a high fat content in the catering. In almost all cases some ingestion from snacks or sports drinks outside of lunch occurred, however the snack foods and amounts were unlikely to have been a main contributor to the fat percentage contribution. From our observations, we believe that if competitive cricket players presented with specific nutrition requirements, they were unlikely to be catered for and this information should be fed back to the coaches.

In our study the average energy cost over a two innings one-day cricket match was 3068 ± 1411 kJ and calculated at 1015 ± 266 $kJ \cdot h^{-1}$. Comparable studies do not exist. These results are the first to have been reported in cricket players, across all cricketing playing positions during one-day cricket matches. Further investigations using GPS for TMA and energy cost analysis in competitive males during one-day cricket matches might be useful towards understanding the actual demands of players. Over time this information could provide coaches, trainers and nutritionists more insight into the potential training and nutrition requirements.

5.9. Recommendations for competitive cricket players and further research.

5.8.1. Recommendations for cricket players and team management.

- Recommend that cricket players continue to bring extra snacks to their games and suggest nutrition education sessions for cricket players that focus on:

1. Achieving adequate pre-match and match carbohydrate intake.

2. Hydration assessment, monitoring and development of personalised fluid plans.

3. Adapting and modify dietary intake during a game to match physical demands.

5.8.2. Recommendations for further research in competetive cricket players.

- Future research should include comprehensive investigations in cricket players that can determine day-to-day hydration status and assess for typical dietary intake and larger nutritional issues.
- Conduct research to specifically investigate hydration practices and hydration status before, and during one-day cricket matches (main objective) and sports drinks habits (secondary objective) in competitive cricket players.
- Conduct observational studies in competitive cricket players that investigate the timing of food and nutrient intake in relation to activity during cricket matches.
- Conduct research that investigates the dietary practices the energy cost of competitive cricket players around training and strength and conditioning sessions.
- Conduct a comprehensive needs assessment and investigation on the nutritional adequacy of catered diets at competitive cricket matches with the view to establish guidelines for cricket catering.

References.

Achten, J. & Jeukendrup, A. E. 2003. Heart rate monitoring - applications and limitations. *Sports Medicine,* 33, 517-538. Available: DOI 10.2165/00007256-200333070-00004.

Ackland, T. R., Lohman, T. G., Sundgot-Borgen, J., Maughan, R. I., Meyer, N. L., Stewart, A. D. & Müller, W. 2012. Current status of body composition assessment in sport: review and position statement on behalf of the ad hoc research working group on body composition health and performance, under the auspices of the I.O.C. Medical Commission. *Sports Medicine,* 42, 227-249.

Ainslie, P. N., Reilly, T. & Westerterp, K. R. 2003. Estimating human energy expenditure - a review of techniques with particular reference to doubly labeled water. *Sports Medicine,* 33, 683-698. Available: DOI 10.2165/00007256-200333090-00004.

Ainsworth, B. E., Haskell, W. L., Herrmann, S. D., Meckes, N., Bassett Jr, D. R., Tudor-Locke, C., Greer, J. L., Vezina, J., Whitt-Glover, M. C. & Leon, A. S. 2011. 2011 Compendium of physical activities: A second update of codes and MET values. *Medicine & Science in Sports & Exercise,* 43, 1575-1581.

Ainsworth, B. E., Haskell, W. L., Leon, A. S., Jacobs, D. R., Montoye, H. J., Sallis, J. F. & Paffenbarger, R. S. 1993. Compendium of physical activities: classification of energy costs of human physical activities. / Abrege des activites physiques, classification des couts energetiques des activites physiques humaines. *Medicine & Science in Sports & Exercise,* 25, 71-80.

Ainsworth, B. E., Haskell, W. L., Whitt, M. C., Irwin, M. L., Swartz, A. M., Strath, S. J., O'brien, W. L., Bassett Jr, D. R., Schmitz, K. H., Emplaincourt, P. O., Jacobs Jr, D. R. & Leon, A. S. 2000. Compendium of physical activities: an update of activity codes and MET intensities. . *Medicine & Science in Sports & Exercise,* 32, S498-s516.

Aragon-Vargas, L. F., Moncada-Jimenez, J., Hernandez-Elizondo, J., Barrenechea, A. & Monge-Alvarado, M. 2009. Evaluation of pre-game hydration status, heat stress, and fluid balance during professional soccer competition in the heat. *European Journal of Sport Science,* 9**,** 269-276.

Armstrong, L. E., Casa, D. J., Millard-Stafford, M., Moran, D. S., Pyne, S. W. & Roberts, W. O. 2007. Exertional heat illness during training and competition. *Medicine & Science in Sports & Exercise,* 39**,** 556-572.

Armstrong, L. E., Maresh, C. M., Castellani, J. W., Bergeron, M. F., Kenefick, R. W., Lagasse, K. E. & Riebe, D. 1994. Urinary indexes of hydration status. *International Journal of Sport Nutrition,* 4**,** 265-279.

Armstrong, L. E., Pumerantz, A. C., Fiala, K. A., Roti, M. W., Kavouras, S. A., Casa, D. J. & Maresh, C. M. 2010. Human hydration indices: Acute and longitudinal reference values. *International Journal of Sport Nutrition and Exercise Metabolism,* 20**,** 145-153.

Armstrong, L. E., Soto, J. a. H., Hacker, F. T., Casa, D. J., Kavouras, S. A. & Maresh, C. M. 1998. Urinary indices during dehydration, exercise, and rehydration. *International Journal of Sport Nutrition,* 8**,** 345-355.

Aughey, R. J. 2011. Applications of GPS technologies to field sports. *International Journal of Sports Physiology & Performance,* 6**,** 295-310.

Australian Institute of Sport. 2016. Available: https://www.ausport.gov.au/ais/nutrition.

Baker, L. 2017. Sweating rate and sweat sodium concentration in athletes: A review of methodology and intra/interindividual variability. *Sports Medicine,* 47**,** 111-128. Available: DOI 10.1007/s40279-017-0691-5.

Bartlett, R. 2003. The science and medicine of cricket: an overview and update. *Journal of Sports Sciences,* 21**,** 733.

Berggren, G. & Christensen, E. 1950. Heart rate and body temperature as indices of metabolic rate during work. *European Journal of Applied Physiology,* 14**,** 255.

Bergström, J., Hermansen, L., Hultman, E. & Saltin, B. 1967. Diet, muscle glycogen and physical performance. *Acta Physiologica Scandinavica,* 71**,** 140-150.

Bernardi, E., Delussu, S. A., Quattrini, F. M., Rodio, A. & Bernardi, M. 2007. Energy balance and dietary habits of America's Cup sailors. *Journal of Sports Sciences,* 25**,** 1153-1160.

Booyens, J. & Hervery, G. R. 1960. The pulse rate as a means of measuring metablic rate in man *Canadian Journal of Physiology and Pharmacology,* 38**,** 1301.

Boyko, E. J. 2013. Observational research--opportunities and limitations. *Journal Of Diabetes And Its Complications,* 27**,** 642-648. Available: DOI 10.1016/j.jdiacomp.2013.07.007.

Brühmann, B. A., Schmidt, M. E. & Steindorf, K. 2014. Assessment of physical activity in epidemiological studies: Are questionnaires obsolete in the era of accelerometry? *GMS Medizinische Informatik, Biometrie und Epidemiologie, Vol 10, Iss 1, p Doc06 (2014)***,** 06. Available: DOI 10.3205/mibe000155.

Burke, L. M. 1995. Practical issues in nutrition for athletes. *Journal of Sports Sciences,* 13**,** S83-s90.

Burke, L. M. 1997. Fluid balance during team sports. *Journal of Sports Sciences,* 15**,** 287-295.

Burke, L. M. 2015a. Nutrition for recovery after training and competition. *In:* Bruke, L. M. & Deakin, V. (eds.) *Clinical sports nutrition.* North Ryde, NSW: McGraw-Hill Australia.

Burke, L. M. 2015b. Preparation for competition. *In:* Burke, L. M. & Deakin, V. (eds.) *Clinical sports nutrition.* 5th ed. North Ryde, NSW: Mc Graw-Hill Australia.

Burke, L. M. & Hawley, J. A. 1997. Fluid balance in team sports: guidelines for optimal practices. *Sports Medicine,* 24**,** 38-54.

Burke, L. M., Hawley, J. A., Wong, S. H. S. & Jeukendrup, A. E. 2011. Carbohydrates for training and competition. *Journal of Sports Sciences,* 29**,** S17-S27.

Burke, L. M., Kiens, B. & Ivy, I. L. 2004. Carbohydrates and fat for training and recovery. *Journal of Sports Sciences,* 22**,** 15-30.

Burke, L. M. & Maughan, R. J. 2015. The Governor has a sweet tooth – Mouth sensing of nutrients to enhance sports performance. *European Journal of Sport Science,* 15**,** 29-40.

Burnett, A. F., Elliott, B. C. & Marshall, R. N. 1995. The effect of a 12-over spell on fast bowling technique in cricket. *Journal of Sports Sciences,* 13**,** 329-341. Available: DOI 10.1080/02640419508732247.

Cade, J., Thompson, R., Burley, V. & Warm, D. 2002. Development, validation and utilisation of food-frequency questionnaires - a review. *Public Health Nutrition,* 5**,** 567-587. Available: DOI 10.1079/phn2001318.

Centers for Disease Control and Prevention. 2017. *About adult BMI* [Online]. Available: https://www.cdc.gov/healthyweight/assessing/bmi/adult_bmi/index.html.

Cheuvront, S. N., Kenefick, R. W. & Zambraski, E. J. 2015. Spot urine concentrations should not be used for hydration assessment: a methodology review. *International Journal of Sport Nutrition & Exercise Metabolism,* 25**,** 293-297.

Cheuvront, S. N. & Sawka, M. N. 2005. Hydration assessment of athletes. *GSSI - Sports Science Exchange,* 97.

Christie, C. J. & King, G. A. 2008. Heart rate and perceived strain during batting in a warm and cool environment. *International Journal of Fitness,* 4**,** 33-38.

Christie, C. J., Todd, A. I. & King, G. A. 2008. Selected physiological responses during batting in a simulated cricket work bout: A pilot study. *Journal of Science & Medicine in Sport,* 11**,** 581-584.

Coutts, A. J., Kempton, T., Sullivan, C., Bilsborough, J., Cordy, J. & Rampinini, E. 2015. Metabolic power and energetic costs of professional Australian football match-play. *Journal of Science and Medicine in Sport,* 18**,** 219-224. Available: DOI 10.1016/j.jsams.2014.02.003.

Crouter, S. E., Churilla, J. R. & Bassett Jr, D. R. 2006. Estimating energy expenditure using accelerometers. *European Journal of Applied Physiology,* 98**,** 601-612. Available: DOI 10.1007/s00421-006-0307-5.

Cummins, C., Orr, R., O'connor, H. & West, C. 2013. Global positioning systems (GPS) and microtechnology sensors in team sports: A systematic review. *Sports Medicine,* 43**,** 1025-1042.

Deakin, V. 2010. Measuring nutritional status of athletes : clinical and research perspectives. *In Burke, L. (ed.), Clinical sports nutrition. 3rd ed, Sydney, McGraw-Hill, c2010, p.18-36.*;.

Deakin, V., Kerr, D. & Boushey, C. 2015. Dietary assessment of athletes: clinical and research perspectives. *In:* Burke, L. M. & Deakin, V. (eds.) *Clinical sports nutrition.* 5th ed. North Ryde, NSW: Mc Graw-Hill Australia.

Devlin, L. H., Fraser, S. F., Barras, N. S. & Hawley, J. A. 2001. Moderate levels of hypohydration impairs bowling accuracy but not bowling velocity in skilled cricket players. / Les niveaux moyens d ' hypohydratation deteriorent la precision du lancer mais pas la vitesse du lancer chez des joueurs de cricket experimentes. *Journal of Science & Medicine in Sport,* 4**,** 179-187.

Duffield, R., Carney, M. & Karppinen, S. 2009. Physiological responses and bowling performance during repeated spells of medium-fast bowling. *Journal of Sports Sciences,* 27**,** 27-35.

Duffield, R. & Drinkwater, E. J. 2008. Time - motion analysis of Test and One-Day international cricket centuries. *Journal of Sports Sciences,* 26**,** 457-464.

Ebine, N., Feng, J., Homma, M., Satoh, S. & Jones, P. J. H. 2000. Total energy expenditure of elite synchronized swimmers measured by the doubly labeled water method. *Eur J appl Physiol,* 83**,** 1-6.

Ferdinands, R., Kersting, U. G., Marshall, R. N. & Stuelcken, M. a. X. 2010. Distribution of modern cricket bowling actions in New Zealand. *European Journal of Sport Science,* 10**,** 179-190.

Finch, C. F., White, P., Dennis, R., Twomey, D. & Hayen, A. 2010. Fielders and batters are injured too: A prospective cohort study of injuries in junior club cricket. *Journal of Science & Medicine in Sport,* 13**,** 489-495.

Fletcher, J. G. 1955. Calories and cricket. *Lancet,* 1**,** 1165-1166.

Fourny, D., Fradette, B., Gounelle, J., Magnenot, M., Villeneuve, A., Daigle, J. & Lacoste, J. 2005. Ball sports (small ball). *In:* Delobel, K. (ed.) *The illustrated encyclopedia of sport.* London, UK: Aurum Press Ltd.

Frost, W. L. & Chalmers, D. J. 2014. Injury in elite New Zealand cricketers 2002-2008: descriptive epidemiology. *British Journal of Sports Medicine,* 48, 1400-1406.

Gamage, J. P., De Silva, A. P., Nalliah, A. K. & Galloway, S. D. R. 2016. Effects of dehydration on cricket specific skill performance in hot and humid conditions. *International Journal of Sport Nutrition & Exercise Metabolism,* 26, 531-541.

Geesmann, B., Mester, J. & Koehler, K. 2014. Energy balance, macronutrient intake, and hydration status during a 1,230 km ultra-endurance bike marathon. *International Journal of Sport Nutrition and Exercise Metabolism,* 24, 497-506. Available: DOI 10.1123/ijsnem.2013-0169.

Gore, C. J., Bourdon, P. C., Woolford, S. M. & Pederson, D. G. 1993. Involuntry dehydration during cricket. *International Journal of Sports Medicine,* 14, 387-395. Available: DOI 10.1055/s-2007-1021197.

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

Haughey, K. 2015. *Sport and active recreation in the lives of New Zealand adults. 2013/14 active New Zealand survey results.* [Online].

Herrmann, S. D. & Pfeiffer, K. A. 2016. New data for an updated youth energy expenditure compendium: an introduction. *Journal of Physical Activity & Health,* 13, S1-S2.

Hill, R. J. & Davies, P. S. W. 2002. Energy intake and energy expenditure in elite lightweight female rowers. / Apports et depenses energetiques chez des rameuses poids leger de haut niveau. *Medicine & Science in Sports & Exercise,* 34, 1823-1829.

Hills, A. P., Mokhtar, N. & Byrne, N. M. 2014. Assessment of physical activity and energy expenditure: an overview of objective measures. *Frontiers in Nutrition, Vol 1 (2014)*. Available: DOI 10.3389/fnut.2014.00005/full
10.3389/fnut.2014.00005.

Hull, A. R. 2018. Energetic costs and metabolic power variables from global positioning system (GPS) units for load monitoring in elite Australian football *Journal of Australian Strength & Conditioning,* 26**,** 53-57.

International Olympic Committee 2011. IOC consensus statement on sports nutrition 2010. *Journal of Sports Sciences,* 29**,** S3-S4. Available: DOI http://dx.doi.org/10.1080/02640414.2011.619349.

Jäger, R., Kerksick, C. M., Campbell, B. I., Cribb, P. J., Wells, S. D., Skwiat, T. M., Purpura, M., Ziegenfuss, T. N., Ferrando, A. A., Arent, S. M., Smith-Ryan, A. E., Stout, J. R., Arciero, P. J., Ormsbee, M. J., Taylor, L. W., Wilborn, C. D., Kalman, D. S., Kreider, R. B., Willoughby, D. S. & Hoffman, J. R. 2017. International society of sports nutrition position stand: protein and exercise. *Journal of the International Society of Sports Nutrition,* 14**,** 1-25.

Jeukendrup, A. E. 2014. A step towards personalized sports nutrition: carbohydrate intake during exercise. *Sports Medicine,* 44**,** 25-33.

Johnston, R. J., Watsford, M. L., Austin, D. J., Pine, M. J. & Spurrs, R. W. 2015. Movement demands and metabolic power comparisons between elite and subelite australian footballers. *Journal of Strength and Conditioning Research,* 29**,** 2738-2744. Available: DOI 10.1519/JSC.0000000000000936.

Johnstone, J. A. & Ford, P. A. 2010. Physiologic profile of professional cricketers. *Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins),* 24**,** 2900-2907.

Johnstone, J. A., Mitchell, A. C. S., Hughes, G., Watson, T. I. M., Ford, P. A. & Garrett, A. T. 2014. The athletic profile of fast bowling in cricket: A review. *Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins),* 28**,** 1465-1473.

Jooste, J., Van Wyk, J. G. U. & Steyn, B. J. M. 2013. The relationship between mental skills and level of cricket participation. *African Journal for Physical, Health Education, Recreation & Dance,* 19**,** 180-192.

Jorgensen, T., Andersen, L. B., Froberg, K., Maeder, U. R. S., Smith, L. & Aadahl, M. 2009. Position statement: Testing physical condition in a population - how good are the methods? *European Journal of Sport Science,* 9**,** 257-267.

Kenefick, R. W., Heavens, K. R., Dennis, W. E., Caruso, E. M., Guerriere, K. I., Charkoudian, N. & Cheuvront, S. N. 2015. Quantification of chromatographic effects of vitamin B supplementation in urine and implications for hydration assessment. *Journal of Applied Physiology,* 119**,** 110-115.

Koehler, K., Braun, H., De Marees, M., Fusch, G., Fusch, C., Mester, J. & Schaenzer, W. 2010. Parallel assessment of nutrition and activity in athletes: Validation against doubly labelled water, 24-h urea excretion, and indirect calorimetry. *Journal of Sports Sciences,* 28**,** 1435-1449.

Koley, S. B. 2011. A study of anthropometric profile of indian inter-university male cricketers. *Journal of Human Sport & Exercise,* 6**,** 427-435.

Koley, S. B., Kumaar, S. & Shadagopan, S. P. 2012. Anthropometric, physical strength, body composition and performance test profiles of inter-district level male cricketers of Punjab, India. *Anthropologist,* 14**,** 445-451.

Koley, S. B., Kumaar, S., Shadagopan, S. P. & Yadav, M. K. 2009. An association of hand grip strength with some anthropometric variables in indian cricket players. / veza između jačine stiska ruke i nekih antropometrijskih varijabli kod indijskih igrača kriketa. *Facta Universitatis: Series Physical Education & Sport,* 7**,** 113-123.

Kreider, R. B., Wilborn, C. D., Taylor, L., Campbell, B., Almada, A. L., Collins, R., Cooke, M., Earnest, C. P., Greenwood, M., Kalman, D. S., Kerksick, C. M., Kleiner, S. M., Leutholtz, B., Lopez, H., Lowery, L. M., Mendel, R., Smith, A., Spano, M., Wildman, R. & Willoughby, D. S. 2010. ISSN exercise & sport nutrition review: research & recommendations. *Journal of the International Society of Sports Nutrition,* 7**,** 7-49.

Larsson, P. 2003. Global positioning system and sport-specific testing. *Sports Medicine,* 33**,** 1093-1101.

Lees, M. J., Bansil, K. & Hind, K. 2016. Total, regional and unilateral body composition of professional English first-class cricket fast bowlers. *Journal of Sports Sciences,* 34**,** 252-258.

Lemmer, H. H. 2012. Individual match approach to bowling performance measures in cricket. *South African Journal for Research in Sport, Physical Education & Recreation (SAJR SPER),* 34**,** 95-103.

Leonard, W. R. 2003. Measuring human energy expenditure: What have we learned from the flex-heart rate method? *American Journal of Human Biology,* 15.

Levine, J. A. 2005. Measurement of energy expenditure. *Public Health Nutrition,* 8**,** 1123-1132.

Livingstone, M. B. 1997. Heart-rate monitoring: the answer for assessing energy expenditure and physical activity in population studies? *The British Journal Of Nutrition,* 78**,** 869-871.

Lord's the Home of Cricket 2017. MCC, the laws of cricket.

Macdonald, D., Cronin, J., Mills, J., M, M. & Stretch, R. 2013a. A review of cricket fielding requirements. *SAJSM,* 25**,** 87-92.

Macdonald, D., Cronin, J., Mills, J. & Stretch, R. 2013b. Wicket-keeping in cricket: A literature review. *International Journal of Sports Science & Coaching,* 8**,** 531-542.

Maddison, R., Yannan, J., Hoorn, S. V., Ni Mhurchu, C., Lawes, C. M. M., Rodgers, A. & Rush, E. C. 2009. Estimating energy expenditure with the RT3 triaxial accelerometer. *Research Quarterly for Exercise & Sport,* 80**,** 249-256.

Magee, P. J., Gallagher, A. M. & Mccormack, J. M. 2017. High prevalence of dehydration and inadequate nutritional knowledge among university and club level athletes. *International Journal of Sport Nutrition & Exercise Metabolism,* 27**,** 158-168.

Maughan, R. J. & Shirreffs, S. M. 2008. Development of individual hydration strategies for athletes. *International Journal of Sport Nutrition & Exercise Metabolism,* 18**,** 457-472.

Maughan, R. J. & Shirreffs, S. M. 2010. Dehydration and rehydration in competative sport. *Scandinavian Journal of Medicine & Science in Sports,* 20**,** 40-47.

Maughan, R. J., Watson, P., Evans, G. H., Broad, N. & Shirreffs, S. M. 2007. Water balance and salt losses in competitive football. *International Journal of Sport Nutrition & Exercise Metabolism,* 17**,** 583-594.

McNamara, D. J., Gabbett, T. J., Naughton, G., Farhart, P. & Chapman, P. 2013. Training and competition workloads and fatigue responses of elite junior cricket players. *International Journal of Sports Physiology & Performance,* 8**,** 517-526.

Medicine., A. C. O. S., Dietetics., A. O. N. A., Canada., D. O. & Statement., J. P. 2016. Nutrition and athletic performance. *Medicine & Science in Sports & Exercise,* 48**,** 543-568.

Meeusen, R. 2014. Exercise, nutrition and the brain. *Sports Medicine,* 44, 47-56.

Micklesfield, L. K., Gray, J. & Taliep, M. S. 2012. Bone mineral density and body composition of South African cricketers. *Journal of Bone and Mineral Metabolism,* 30, 232-237. Available: DOI 10.1007/s00774-011-0310-8.

Montain, S. J. 2008. Hydration recommendations for sport 2008. *Current Sports Medicine Reports (American College of Sports Medicine),* 7, 187-192.

Moore, D. R., Robinson, M. J., Fry, J. L., Tang, J. E., Glover, E. I., Wilkinson, S. B., Prior, T., Tarnopolsky, M. A. & Phillips, S. M. 2009. Ingested protein dose response of muscle and albumin protein synthesis after resistance exercise in young men. *American Journal of Clinical Nutrition,* 89, 161-168. Available: DOI 10.3945/ajcn.2008.26401.

Mujika, I. & Burke, L. M. 2011. Nutrition in teams sports. *Ann Nutr Metab,* 57, (suppl 2):26-35. Available: DOI 10.1159/000322700.

New Zealand Ministry of Health. 2015. *Eating and activity guidelines* [Online]. Available: http://www.health.govt.nz/our-work/eating-and-activity-guidelines.

Noakes, T. D. & Durandt, J. J. 2000. Physiological requirements of cricket. *Journal of Sports Sciences,* 18, 919-929.

Noorbhai, M. H. & Noakes, T. D. 2015. Advances in cricket in the 21st century: Science, performance and technology. *African Journal for Physical, Health Education, Recreation & Dance,* 21, 1310-1320.

Nuccio, R., Barnes, K., Carter, J. & Baker, L. 2017. Fluid balance in team sport athletes and the effect of hypohydration on cognitive, technical, and physical performance. *Sports Medicine,* 47, 1951-1982.

Oppliger, R. A. & Bartok, C. 2002. Hydration testing of athletes. *Sports Medicine,* 32**,** 959-971.

Oppliger, R. A., Magnes, S. A., Popowski, L. A. & Gisolfi, C. V. 2005. Accuracy of urine specific gravity and osmolality as indicators of hydration status. *International Journal of Sport Nutrition & Exercise Metabolism,* 15**,** 236.

Orchard, J. W., Kountouris, A., Sims, K. J., Orchard, J., Beakley, D. T. & Brukner, P. D. 2015. Change to injury profile of elite male cricketers in the T20 era. *New Zealand Journal of Sports Medicine,* 42**,** 13-17.

Osgnach, C., Poser, S., Bernardini, R., Rinaldo, R. & Di Prampero, P. E. 2010. Energy cost and metabolic power in elite soccer: A new match analysis approach. *Medicine & Science in Sports & Exercise,* 42**,** 170-178.

Osterberg, K. L., Horswill, C. A. & Baker, L. B. 2009. Pregame urine specific gravity and fluid Intake by national basketball association players during competition. *Journal of Athletic Training,* 44**,** 53-57.

Parnell, W., Heath, A., Brown, R., Walker, H., Gray, A., C., B. & Fleming, L. 2011. *Methodology report for the 2008/09 New Zealand Adult Nutrition Survey.* Available: http://www.health.govt.nz/publication/methodology-report-2008-09-nz-adult-nutrition-survey.

Penn, M. J. & Spratford, W. 2012. Are current coaching recommendations for cricket batting technique supported by biomechanical research? *Sports Biomechanics,* 11**,** 311-323.

Petersen, C., Pyne, D., Dawson, B., Portus, M. & Kellett, A. 2010. Movement patterns in cricket vary by both position and game format. *Journal of Sports Sciences,* 28**,** 45-52.

Petersen, C., Pyne, D., Portus, M. & Dawson, B. 2009a. Validity and reliability of GPS units to monitor cricket-specific movement patterns. *International Journal of Sports Physiology & Performance,* 4**,** 381-393.

Petersen, C., Pyne, D., Portus, M. & Dawson, B. 2011. Comparison of player movement patterns between 1-day and test cricket. *Journal of Strength & Conditioning Research,* 25**,** 1368-1373.

Petersen, C., Pyne, D., Portus, M., Karppinen, S. & Dawson, B. 2009b. Variability in movement patterns during one say internationals by a cricket fast bowler. *International Journal of Sports Physiology & Performance,* 4**,** 278-281.

Phillips, S. M., Sproule, J. & Turner, A. P. 2011. Carbohydrate ingestion during team games exercise. *Sports Medicine,* 41**,** 559-585.

Phillips, S. M. & Van Loon, L. J. 2011. Dietary protein for athletes: From requirements to optimum adaptation. *Journal of Sports Sciences,* 29**,** S29-S38.

Plasqui, G. & Westerterp, K. R. 2007. Physical activity assessment with accelerometers: An evaluation against doubly labeled water. *Obesity (19307381),* 15**,** 2371-2379.

Portus, M. R., Sinclair, P. J., Burke, S. T., Moore, D. J. A. & Farhart, P. J. 2000. Cricket fast bowling performance and technique and the influence of selected physical factors during an 8-over spell. *Journal of Sports Sciences,* 18**,** 999-1011.

Pote, L. & Christie, C. J. 2014. Physiological and perceptual demands of high intensity sprinting between the wickets in cricket. *International Journal of Sports Science & Coaching,* 9**,** 1375-1382.

Rawstorn, J. C., Maddison, R., Ali, A., Foskett, A. & Gant, N. 2014. Rapid directional change degrades GPS distance measurement validity during intermittent intensity running. *PLoS ONE,* 9**,** 1-6. Available: DOI 10.1371/journal.pone.0093693.

Rudkin, S. T. & O'Donoghue, P. G. 2008. Time-motion analysis of first-class cricket fielding. *Journal of Science & Medicine in Sport,* 11**,** 604-607.

Ryan, J. & Gormley, J. 2013. Measurement of energy expenditure by activity monitors. *Physical Therapy Reviews,* 18**,** 239-262. Available: DOI 10.1179/1743288X13Y.0000000063.

Sawka, M. N., Burke, L. M., Eichner, E. R., Maughan, R. J., Montain, S. J. & S., S. N. 2007. Exercise and fluid replacement. *Medicine & Science in Sports & Exercise,* 39**,** 377-390.

Scanlan, A. T., Berkelmans, D. M., Vickery, W. M. & Kean, C. O. 2016. A review of the internal and external physiological demands associated with batting in cricket. *International Journal of Sports Physiology & Performance,* 11**,** 987-997.

Shaw, G., Nana, A. & Broad, E. M. 2015. Physique assessment of the athlete. *In:* Burke, L. M. & Deakin, V. (eds.) *Dietary assessment of athletes: Clinical and research perspectives.* Mc Graw-Hill Australia.

Shephard, R. & Aoyagi, Y. 2012. Measurement of human energy expenditure, with particular reference to field studies: an historical perspective. *European Journal of Applied Physiology,* 112**,** 2785-2815.

Shirreffs, S. M. 2003. Markers of hydration status. *European Journal of Clinical Nutrition,* 57**,** S6-S9. Available: DOI 10.1038/sj.ejcn.1601895.

Shirreffs, S. M. & Sawka, M. N. 2011. Fluid and electrolyte needs for training, competition, and recovery. *Journal of Sports Sciences,* 29**,** S39-S46.

Silva, R. M., Manage, A. B. W. & Swartz, B. 2015. A study of the powerplay in one-day cricket. *European Journal of Operational Research,* 244**,** 931-938.

Soo, K. & Naughton, G. 2007. The hydration profile of female cricket players during competition. *International Journal of Sport Nutrition & Exercise Metabolism,* 17, 14-26.

Sports Dietitians Australia. 2016. *Food for your sport-cricket* [Online]. Available: https://www.sportsdietitians.com.au/factsheets/food-for-your-sport/food-for-your-sport-cricket/.

Sports Dietitians Australia 2017. Cricket. [Online]. Available: https://www.sportsdietitians.com.au/factsheets/food-for-your-sport/food-for-your-sport-cricket/

Stockley, L. 1985. Changes in habitual food-intake during weighed inventory survery and duplication diet collections - a short review. *Ecology of Food and Nutrition,* 17, 263-269. Available: DOI 10.1080/03670244.1985.9990901.

Stretch, R. A. 1987. Anthropometric profile of first-class cricketers. *Physical Education and Recreation,* 10, 65-75.

Stretch, R. A. 1991. Anthropometric profile and body composition changes in first-class cricketers. / Antropometriese profiel en veranderinge in liggaamsamestelling van goeie krieketspelers. *South African Journal for Research in Sport, Physical Education & Recreation,* 14, 57-64.

Stronach, B. J., Cronin, J. B. & Portus, M. R. 2014a. Part 1: Biomechanics, injury surveillance, and predictors of injury for cricket fast Bowlers. *Strength & Conditioning Journal,* 36, 65-72.

Stronach, B. J., Cronin, J. B. & Portus, M. R. 2014b. Part 2: Mechanical and anthropometric factors of fast bowling for cricket, and implications for strength and conditioning. *Strength & Conditioning Journal,* 36, 53-60.

Stuelcken, M., Pyne, D. & Sinclair, P. 2007. Anthropometric characteristics of elite cricket fast bowlers. *Journal of Sports Sciences,* 25**,** 1587-1597.

Tam, N. & Noakes, T. D. 2013. The quantification of body fluid allostasis during exercise. *Sports Medicine,* 43**,** 1289-1299.

Taylor, J., Wright, A., Dischiavi, S., Townsend, M. & Marmon, A. 2017. Activity demands during multi-directional team sports: a systematic review. *Sports Medicine,* 47**,** 2533-2551.

Thomas, D. T., Erdman, K. A. & Burke, L. M. 2016. Position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and athletic performance. *Journal of the Academy of Nutrition & Dietetics,* 116**,** 501-528.

Tipton, K. D. 2011. Symposium2: Exercise and protein nutrition efficacy and consequences of very-high-protein diets for athletes and exercisers. *Proceedings of the Nutrition Society,* 70**,** 205-214.

Troiano, R. P., Berrigan, D., Dodd, K. W., Masse, L. C., Tilert, T. & Mcdowell, M. 2008. Physical activity in the United States measured by accelerometer. *Medicine and Science in Sports and Exercise,* 40**,** 181-188. Available: DOI 10.1249/mss.0b013e31815a51b3.

Trost, S. G., Kerr, L. M., Ward, D. S. & Pate, R. R. 2001. Physical activity and determinants of physical activity in obese and non-obese children. *International Journal of Obesity,* 25**,** 822-829. Available: DOI 10.1038/sj.ijo.0801621.

Turocy, P. S., Depalma, B. F., Horswill, C. A., Laquale, K. M., Martin, T. J., Perry, A. C., Somova, M. J. & Utter, A. C. 2011. National Athletic Trainers' Association Position Statement: Safe weight loss and maintenance practices in sport and exercise. *Journal of Athletic Training,* 46**,** 322-336.

Vickery, W., Dascombe, B., Baker, J., Higham, D., Spratford, W. & Duffield, R. 2014a. Accuracy and reliability of gps devices for measurement of sports-specific movement patterns related to cricket, tennis, and field-based team sports. *Journal of Strength & Conditioning Research,* 28**,** 1697-1705.

Vickery, W., Dascombe, B. & Duffield, R. 2014b. Physiological, movement and technical demands of centre-wicket Battlezone, traditional net-based training and one-day cricket matches: a comparative study of sub-elite cricket players. *Journal of Sports Sciences,* 32**,** 722-737.

Vickery, W., Dascombe, B. & Duffield, R. 2017. The association between internal and external measures of training load in batsmen and medium-fast bowlers during net-based cricket training. *International Journal of Sports Physiology & Performance,* 12**,** 247-253.

Vickery, W., Dascombe, B., Duffield, R., Kellett, A. & Portus, M. 2013. Battlezone: An examination of the physiological responses, movement demands and reproducibility of small-sided cricket games. *Journal of Sports Sciences,* 31**,** 77-86.

Voitkevica, L., Pontaga, I., Timpmann, S. & Ööpik, V. 2014. Pre-training hydration status of well-trained soccer player in moderate temperature autumn and cool winter *Baltic Journal of Sport & Health Sciences* 95**,** 57-63.

Watsford, M. L. & Doğramaci, S. N. 2006. A comparison of two different methods for time-motion analysis in team sports. *International Journal of Performance Analysis in Sport,* 6**,** 1-1.

Williams, C. & Rollo, I. 2015. Carbohydrate nutrition and team sport performance. *Sports Medicine,* 45**,** 13-22.

Woodruff, S. J. & Meloche, R. D. 2013. Energy availability of female varsity volleyball players. *International Journal of Sport Nutrition & Exercise Metabolism,* 23**,** 24-30.

Appendix.

Appendix A: Study information sheet.

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Nutrition for High Performing Cricket Players

INFORMATION SHEET

We would like to invite you to take part in the Nutrition for High Performing Cricket Players study, which aims to establish a situational awareness of nutritional issues in high performing cricket players. This study is being conducted by Shelley McDonald (New Zealand Registered Dietitian and MSc in Human Nutrition student, Massey University), Corey Payne (MSc Nutrition and Dietetics student, Massey University), Dr Kathryn Beck and Dr Pamela von Hurst (School of Food and Nutrition, Massey University), and Dr Andrew Foskett (School of Sport and Exercise, Massey University) in collaboration with Auckland Cricket. Please read this Information Sheet carefully before deciding whether or not to participate.

Researcher(s) Introduction

The lead researchers for this study are Shelley McDonald and Dr Kathryn Beck.

Shelley McDonald
NZ Registered Dietitian
School of Food and Nutrition, Massey University
Email: s.m.mcdonald1@massey.ac.nz
Phone: 021 903 422

Dr Kathryn Beck
NZ Registered Dietitian and Lecturer
School of Food and Nutrition, Massey University Massey University, Albany
Email: k.l.beck@massey.ac.nz
Phone: (09) 414 0800 ext 43662

Project Description and Invitation

Why is this research important?
Cricket is a physical and mentally demanding game. Rates of injury appear to be rising; particularly stress fractures in bowlers. Optimal nutrition is important for the prevention of injury, and for optimal performance.

This study aims to explore factors relating to cricket performance in high performance male and female cricket players. To achieve this we will assess energy intake, energy expenditure, hydration status and self-reported fatigue during cricket matches; we will determine bone mineral density and stress fracture risk using Dual-energy X-ray Absorptiometry (DXA) and questionnaires; and we will compare body composition pre and post season using bioelectrical impedance analysis.

Participant Identification and Recruitment

Who are we looking for?

This study is recruiting male and females involved in Auckland Cricket training and performance programs (Auckland Aces, Auckland Hearts, Developing Future Aces) during the period August 2015 to April 2016. There is no exclusion criteria, so all cricket players involved in these squads are invited to participate in this study.

Project Procedures
What is going to happen?

Please read this Information Sheet carefully. If you decide to participate in this study you will be asked to sign a Consent Form. This study is completely voluntary and if you decide not to participate in the study, there will be no negative consequences for the remainder of your time with Auckland Cricket.

If you choose to participate, you will visit Massey University on one occasion in early September. Throughout the season, you will be observed at one or two cricket matches. During the season, we will ask you to complete a questionnaire each month related to injury risk. At the end of the season (April), we will assess your body composition. This will be undertaken during one of your usual training sessions. The total amount of time (outside normal training and playing time) needed for this study is approximately 3hours.

Massey University (this appointment will take approximately 2 hours)

We will ask you to attend Massey University during one of your normal training sessions. For the two hours before your appointment, we will ask you to avoid eating, drinking or participating in physical activity. A small snack will be provided at the commencement of your appointment. We will ask you to do the following at this appointment:

1. Complete a **demographic health questionnaire** including questions on age, gender, lifestyle choices, physical activity (intensity, frequency), medical history, injuries, medications, supplement use.
2. Complete a **dietary questionnaire** focusing on usual dietary intake, as well as historical dietary intake with a focus on calcium intake.
3. Complete a **nutrition knowledge, attitudes and practices** questionnaire.
4. **Bone density measurements** using a DXA machine.
5. **Body composition measurements** including:
    a. Height and weight, measured using an electronic scale and stadiometer.
    b. Lean body mass and body fat percentage, measured using a bioelectrical impedance analysis machine (InBody 230). The machine measures body composition by running a very low level of electrical current through your body as you stand on the machine. You will not feel this current.

From the night prior to your selected cricket match:

From 10pm prior to your observed cricket match, we will ask you to write down everything you eat or drink on forms provided.

On the morning of your selected cricket match we will ask you to:

1. Continue to record all you eat or drink on the forms provided (up until the start of your match).
2. Urine sample's – we will ask you to collect an upon waking urine sample and place into the labelled container provided, We would ask that you collect, measure and document any further urine output before arriving to the match venue.

During cricket matches (throughout the duration of a 50 over cricket match – over 6 hours):

You are likely to be observed during the course of one to two 50 over cricket matches, however research assistants maybe present at other matches you may be involved in. The number of times research assistants are present will depend to a small extent on players selected to play particular matches. We ask that you participate in your cricket match as you would do normally, without

changing anything that you would normally do. During this time the researchers the following data will be collected:

1. **Hydration**: As part of hydration assessment we will request pre and post match weights (in undergarments). You will be asked to collect all urine passed into a small container throughout the duration of the match. Prior to and following bowel motions, research assistants will take body weight measurements (in cricket attire).
2. **Energy expenditure**: You will be asked to wear a small, unobtrusive GPS/accelerometer monitor throughout the entire match including breaks.
3. **Dietary intake**: All food and fluid eaten will be observed and recorded over the duration of the observed match. We will photograph your food at the beginning of the day, any leftovers at the end of the day, and before and after snacks and meals (if applicable). Some of your food may be labelled with identification stickers (drink bottles and packaged food) or weighed to increase the accuracy of our observations.
4. **Self-reported fatigue scales questionnaire:** You will be asked to complete a short fatigue questionnaire 3-5 x - pre, during and post-match. These will be very short and will not interfere with match performance.

Throughout the season:

Via email we will send you a short injury questionnaire to complete monthly over the season. We will ask you to complete the questionnaire and email back to us. The questionnaire will take no longer than 5 minutes to complete.

At the end of the season:

We will take **body composition** measurements including height and weight, and lean body mass and body fat percentage, measured using a bioelectrical impedance analysis machine. This will be done at a regular training session.

What are the benefits and risks of taking part in this study?

You will receive individualized body composition data and be able to assess any change in your body composition from the beginning to end of training.

We will use the Hologic DXA machine to estimate bone mineral density and bone mineral content of your hip and femur. The DXA has X-ray beams at 2 different energies and while no dose of radiation is harmless this dose is very low and unlikely to cause harm. The total effective dose of radiation to which you will be exposed to is 10 microsieverts (μSv), which is much lower than the range normally used in medical diagnostics. To place in perspective, the amount of radiation you are exposed to during a flight to the United Kingdom return is 100 μSv and from a dental Xray 50 μSv. The room is private and you can enter the DXA room in complete privacy. We will provide you with a gown to wear during this measurement. The staff who do this are certified in bone densitometry scanning. If the results of your bone density fall out of the normal reference ranges you will be informed and sent the results to take to your Medical Practitioner for follow up, alternatively we can contact your medical practitioner on your behalf.

Participating in the study will contribute to the limited information available on nutrition status in high performing cricket players. The results of the study may influence future nutrition interventions at Auckland cricket.

Social or cultural discomfort may be caused from having body composition measures taken. The body composition assessment will require you to wear minimal clothing, e.g. shorts and a t-shirt; if or cultural or religious reasons you need to remain covered (eg. Turban) we will respect this. All participants will be treated with respect and measurements will be conducted in privacy. You may also be accompanied by a support person if preferred. Collection of urine may raise cultural concerns for some. All urine will be kept separate from food items during storage.

Data Management

How will the data be used?

The data collected from this study will be used to:

- Investigate the energy balance, hydration status, and self-reported fatigue levels of cricket players during a 50 over cricket match.
- Determine predictors of bone mineral density and injury/stress fracture risk.
- Determine body composition pre and post season.

The data will only be used for the purposes of this study. Only the investigators and administrators of the study will have access to personal information and this will be kept secure and strictly confidential.

How will the data be stored?

Participants will be identified only by a unique study identification code and all data forms will use this code. The data forms will be stored in a locked filing cabinet in the Human Nutrition Research Unit, Albany Campus, Massey University. The electronic data will be stored on computers, which are protected by passwords, in locked offices of the Human Nutrition Research Unit. Consent forms will be stored separately to data forms in a locked office in the Human Nutrition Research Unit, Albany Campus, Massey University.

Results of this study may be published or presented at conferences or seminars; however, no individual will be identifiable.

How will the data be disposed of?

At the end of this study the list of participants and their study identification codes will be disposed of. Any raw data on which the results of the project depend will be retained in secure storage for 10 years, after which time it will be destroyed.

How will I access a summary of the project findings?

A summary of the project findings will be available to all study participants and you will be sent this information via email. If you leave Auckland Cricket before the results are available you are welcome to contact Shelley McDonald (contact details as below) to request the results be provided via an alternative contact method.

Who is funding this research?

Auckland Cricket and Massey University

Support Processes

If there are any DXA results outside of the normal reference range, you will be contacted and be given the option to collect your result for follow up with your Medical Practitioner, alternatively we can advise your Medical Practitioner on your behalf.

Participant's Rights

You are under no obligation to accept this invitation. If you decide to participate, you have the right to:

- Decline to answer any particular question.
- Ask any questions about the study at any time during participation.
- Withdraw from the study at any time during participation.
- Provide information on the understanding that your name will not be used unless you give permission to the researcher.
- Be given access to a summary of the study findings when it is concluded.

Project Contacts

If you have any further questions or concerns about the project, either now or in the future, please contact either:

Shelley McDonald	Dr Kathryn Beck
School of Food and Nutrition, Massey University	School of Food and Nutrition, Massey University
Email: s.m.mcdonald1@massey.ac.nz	Email k.l.beck@massey.ac.nz
Phone: 021903 422	Phone (09) 4140800 ext 43662

Committee Approval Statement

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application SOA 15/46. If you have any concerns about the conduct of this research, please contact Mr Jeremy Hubbard, Acting Chair, Massey University Human Ethics Committee: Southern A, telephone 04 801 5799 x 63487, email humanethicsoutha@massey.ac.nz.

Compensation for Injury

If physical injury results from your participation in this study, you should visit a treatment provider to make a claim to ACC as soon as possible. ACC cover and entitlements are not automatic and your claim will be assessed by ACC in accordance with the Accident Compensation Act 2001. If your claim is accepted, ACC must inform you of your entitlements, and must help you access those entitlements. Entitlements may include, but not be limited to, treatment costs, travel costs for rehabilitation, loss of earnings, and/or lump sum for permanent impairment. Compensation for mental trauma may also be included, but only if this is incurred as a result of physical injury.

If your ACC claim is not accepted you should immediately contact the researcher. The researcher will initiate processes to ensure you receive compensation equivalent to that to which you would have been entitled had ACC accepted your claim.

Appendix B: Consent form.

Nutrition for High Performance Cricket Players

PARTICIPANT CONSENT FORM – INDIVIDUAL

I have read the Information Sheet and have had the details of the study explained to me.

My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I agree to participate in this study under the conditions set out in the Information Sheet.

Signature: .... **Date:** ....

Full Name - printed ....

Appendix C: Phase two appointment and instruction letter.

Hi NAME

Thank you for participating in the 'Nutrition for High Performing Cricketers Study'.

Your appointment has been scheduled for the DATE at TIME and should take no more than 2 hours.

<u>Important information about your visit:</u>

- Ensure that you **do not** eat, drink or exercise for the two hours before your appointment.
- Refrain from consuming excessive amounts of alcohol the night before your appointment and for the time before your appointment.
- Remove all jewellery and piercings before arriving (if possible, leave them at home).
- Your clothing should be light and contain no metal artefacts such as buttons, zips etc. A gown will be provided for you to wear during your bone scan.
- Please bring along any supplements you are currently taking (or alternatively take a photo on your cell phone of the supplements you are taking and bring along).
- Please try to be on time for your appointment as our days are very tightly scheduled. If you are running late, please try to let us know by calling/texting Shelley on 021 903 422 (leave a message if no one answers).

<u>Directions to the Human Nutrition Research Unit, Massey University, Albany:</u>

Building 27,
Entrance 4
The Station Crescent
Off Albany Highway
Albany
0632

- From SH1 – exit at Greville Road and head towards Massey University.
- Drive past the main Massey Campus on your left (entrances 1 and 2).
- Turn left at the crossroads onto Albany Highway (signposted Greenhithe and Waitakere).
- You will pass Albany High School.
- Entrance 4 is on the left at the first roundabout.
- Once through Entrance 4, follow the road to the left and keep the car park on your right.
- Turn left (The Station Crescent) and then left again back up the hill.
- Building 27 is on your right hand side. You may park in the spaces available on the left hand side.

- Please download and print the attached file for directions to where we are, and allow extra time in your journey to find us. If you have trouble finding us please call the above number (leave a message if no one answers).

If you have any further questions or any problems, please call the above number, or email us at cricketstudy@massey.ac.nz

Thank you and we look forward to seeing you soon!

Shelley McDonald and Corey Payne
Nutrition for High Performing Cricketers Study
021 903 422

Appendix D: Demographic and lifestyle questionnaire.

MASSEY UNIVERSITY
COLLEGE OF SCIENCES
TE WĀHANGA PŪTAIAO

Participant ID number:......................

Nutrition for high performing cricket players

Participant Information form and medical history

Section 1: Demographics and lifestyle

1) What is your age in years? ____

2) Which ethnic group do you belong to? Tick whichever applies to you (you may tick more than one box).

- ☐ New Zealand European
- ☐ Maori
- ☐ Samoan
- ☐ Cook Island Maori
- ☐ Tongan
- ☐ Niuean
- ☐ Chinese
- ☐ Indian
- ☐ Other *Please state which ethnicity*_______________________

3) Which country were you born in?

____

4) If you live in New Zealand but were not born here, when did you first arrive to live in New Zealand?

Month (e.g. February)___________ Year (e.g.2000) ______

5) How would you describe your eating pattern?

Eat a variety of all foods, including animal products ☐

Eat eggs, dairy, fish and chicken but avoid other meats ☐

Eat eggs and dairy products but avoid all meats and fish ☐

Eat eggs but avoid dairy products, all meats and fish ☐

Eat no animal products ☐

Other ☐

Please specify ____

6) Do you follow any diet for cultural or religious reasons?

Yes ☐ **No** ☐

If yes, what type of diet do you follow? ________________________________

7) Have you been on a diet in the last year?

Yes ☐ **No** ☐

If so, please describe the type of diet you were on and how long you adhered to it

____

8) Do you currently smoke?

Yes ☐ **No** ☐

If so, how many cigarettes would you average per week?

0-10 ☐ 11-20 ☐ 21-30 ☐ 31-40 ☐ 41-50 ☐ 51-60 ☐ 61-70 ☐

71-80 ☐ 80+ ☐

9) Have you ever smoked for an extended period (6 months or more) at any point up until now?

Yes ☐ **No** ☐

If so, how many months did you continuously smoke for?

6-12 ☐ 13-24 ☐ 24-30 ☐ 31-36 ☐ 37-42 ☐ 43-48 ☐ 48+ ☐

10) How many standard alcoholic drinks do you consume during a normal week? (Please use the diagram below to help you answer this question)

None ☐ 1-7 ☐ 8-14 ☐ 15-21 ☐ 22-28 ☐ 29+ ☐

11) Do you have any food intolerances or allergies?

Yes ☐ **No** ☐

Please specify

____

Section 3: Training

1) Which position do you play?

Batsman ☐
Bowler; Spin ☐ Pace ☐
All rounder ☐
Wicket keeper ☐

2) Please describe your usual weekly training during the season?

	Details of type of training	**Time**
example	*Skills training + weight training,* *Net session (bowling or batting)*	2 hours 30 minutes
Monday		
Tuesday		
Wednesday		
Thursday		
Friday		
Saturday		
Sunday		

3) On average per day how much training time per day is spent outdoors, with at least one part of your body (e.g hands, feet, arms, and legs) exposed to direct sunlight (without sunscreen)?

____

4) On average, how much non-training time per day is spent outdoors, with at least one part of your body (e.g hands, feet, arms, and legs) exposed to direct sunlight (without sunscreen)?

____

5) On average**,** how much time in total (including training) would you spend outdoors during the offseason with at least one part of your body (e.g hands, feet, arms, and legs) exposed to direct sunlight (without sunscreen)?

____

Section 3: Health

1) Do you have or have you ever had any acute or chronic illness (e.g. asthma, Crohn's disease, frequent colds)?

Yes ☐ **No** ☐

Details on diagnosis, including when and by whom, and any treatment received

____

____

____

2) Have you ever been diagnosed with low Vitamin D levels, or vitamin D deficiency?

Yes ☐ **No** ☐

Details on diagnosis, including when and by whom, and any treatment received

____

____

____

Complete question 3 if you are female (otherwise go to question 4)

3) Please comment on your menstrual status

Are you menstruating? **Yes** ☐ **No** ☐

If you answered yes is your menstruation regular? **Yes** ☐ **No** ☐

If you answered no, when was your last menstrual period?

____

____

Are you currently using birth control contraception? **Yes** ☐ **No** ☐

If you answered yes please explain further: the type and or name of the contraception that you are using (eg. oral birth control pills, injectable contraception, intrauterine contraception) and for how long you have used this form of contraception

____

____

If you have used injectable contraception in the past, please note the duration of time for which you used?

____

____

4) Have you ever been treated for stress fractures?

Yes ☐ **No** ☐

(Details on diagnosis (including when and by whom, severity and any treatment received)

____

____

____

5) Does anyone in your immediate family (that is, blood relatives) have osteoporosis that you are aware of?

Yes ☐ **No** ☐

If yes, please tell us the gender of the person, and the age at which they were diagnosed and their relationship to you?

____

____

____

Section 4: Supplements

1) Did you take any vitamin and/or mineral capsules/tablets at any time during the past year?

Yes ☐ **No** ☐

If yes, please list the brand name of the supplement, the type of supplement, the number taken, the frequency of intake and the dose (including units) and the reason for taking?

eg. Healtheries Iron & vitamin C, 1 taken every 2nd day, ferrous gluconate (170mg) providing elemental iron (20mg) and vitamin C (40mg), taken because I was feeling tired

If you can't remember the details of the supplements, please email us with the brand, type and dose so we can record these on your file.

Email requested ☐ **Email received** ☐

____

____

____

____

2) Did you take any sports supplements at any time during the past year (including sports drinks, sports gels sports bars, liquid meal supplements, protein supplements, herbal supplements)?

Yes ☐ **No** ☐

If yes, please list the brand name / type of sports supplement, the frequency of intake and the dose (including units), and the reason for taking.

eg. Powerade (750ml) taken every day during evening training (5x/week) for the past 3 years

____

____

____

____

3) Did you take any other dietary supplements during the past year? (for example, omega-3 tablets, evening primrose oil, performance enhancers, herbal supplements)

Yes ☐ **No** ☐

If yes, please list the brand name of the supplement, the type of supplement, the number taken and the frequency of intake and the dose (including units)?

eg. Omega 3 supplements, 1 capsule taken per day for the past 3 months, contains 180mg eicosapentanoic acid & 120mg docosahexaenoic acid 1000mg, took for aching joints

____

____

____

____

Appendix E: Pre match instruction sheet.

The night before the game

- Record any food and fluid that you eat and drink in the ***Food Diary*** sheet from 10pm until you arrive at the game the next morning.

- Put small container by the toilet

→

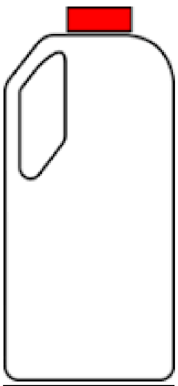
Morning of the game

- The very **first upon waking** morning urine: Pee some into small container, (the rest in toilet) and place in zip- lock bag.

→

- We will give you a large urine collecting bottle. It will probably look like this.

↘



- Pee into this bottle from now on (After your first upon waking urine).

<u>What you take to the game</u>

- Brown paper bag, it should contain:

  - Any food or drinks that you are taking to the game
  - Any wrappers or empty containers from any thing you may have already eaten or drunk before the game that morning
  - Your food and fluid diary

- Urine sample with yellow lid in zip lock bag
- Large urine bottle (with urine collected)

Appendix F: Food record.

NUTRITION FOR HIGH PERFORMING CRICKET PLAYERS STUDY

How to complete a Food and Fluid Record.

Please complete a food and fluid diary from Friday ***10pm*** the night before your match until game start time the following day. It is important that we obtain as accurate infomormation as possible regarding food and fluds consumed. Below are some basic instructions outlining how to complete a food and fluid diary.

1. Record **everything** that you eat and drink (that which was actually consumed)

eg. *2 slices of molenburg multigrain toast slice toast with 2 tsp of olivani spread and 3 tsp of store brought strawberry jam.*

2. Record **how** the food was prepared: pan or deep fried in oil or butter, roasted, steamed, boiled, grilled, microwave, stewed, barbecued, poached, baked.
For example:

- *1 x hand length sized serve (150g) of steamed fish*
- *1 x hand length sized serve (150g) pan fried fish with 1 tsp of olive oil*
- *2 x grilled lamb chops, ½ cup boiled carrots, ½ cup boiled broccoli, 3 egg sized boiled potatos*.

3. Give as many **details** as possible about the *type* of food that you eat.
eg. *Trim or whole milk, brown or white bread, plain or chocolate biscuits*.
- If you consume a packaged food include the brand name:

- *1 cup of Sanitaruim sultana bran with 150 ml of "light blue"*
- *Anchor milk and 2 heaped dessert spoons of Yoplait natural (no sugar added) yoghurt.*

4. Record the **amount** that was consumed.

- *1 bowl of sanitarium cornflakes, 2 teaspoons of sugar + 1 250 ml glass of anchor calci trim milk*
- *1 medium handful of roasted unsalted mixed nuts*

If the weight of a food item consumed was easily obtained from the packaging you may include this, for example:

- *1 x 40g Tasti protein bar, peanut butter flavour*
- *150ml pottle of regular fresh and fruity yoghurt.*

5. Record if you were eating out, or if you purchased take outs, eg café, restaurant, bakery, fish and chip shop followed by what you consumed:

eg. *At café: 1 café sized chocolate chip muffin with 1 medium cup sized soy milk hot chocolate*.

6. Record the **timing** of eating and drinking: *see time slot on Food and Fluid Diary*

7. If you are in rush or eating out and complete your diary retrospectively, take photo's of your food to refer to later and record the amount you actually ate.

NUTRITION FOR HIGH PERFORMING CRICKET PLAYERS STUDY
FOOD AND FLUID RECORD.

Name ____________________ Date ____________________________

TIME	***MEALS / SNACKS***	***DRINKS***

Appendix G: Batting form.

Batting Order, Batting Times, Batting RPE

Bat Order	ID	Time in	Time out	Pre RPE score	Post RPE score
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					
11.					
12th					

Note any change in batting order

Date: ……………………………

Appendix H: Bowling record.

Bowling time line Location/Venue Date:

Over	Participant	Time in	Time out

Appendix I: Match temperature.

Time and Temperature Recordings

Batting innings: 1st / 2nd

Batting inning **START time** ……………………………………

- Temperature …………………………………………

- Humidity …………………………………………….

Time at one hour & 10 minutes (~17 overs)………………

- Temperature…………………………………………

- Humidity……………………………………………

Time at two hours & 20 minutes (~ 34 overs)…………..

- Temperature………………………………………..

- Humidity…………………………………………..

Batting innings **END time** …………………………………….

- Temperature………………………………………..

- Humidity…………………………………………..

Date: ………………………………

Time and Temperature Recordings

Fielding innings: 1st / 2nd

Fielding inning **START time** ……………………………………

- Temperature …………………………………………….
- Humidity ………………………………………………..

Time at one hour & 10 minutes (~17 overs)………………

- Temperature…………………………………………….
- Humidity………………………………………………..

Time at two hours & 20 minutes (~ 34 overs)…………..

- Temperature…………………………………………..
- Humidity……………………………………………….

Fielding innings **END time** ………………………………………

- Temperature…………………………………………..
- Humidity……………………………………………….

Appendix J: U_{SG} and urine output record.

U_{SG} and Urine Output recording form DATE……………… Location/Venue………………………...

Name	ID	Position	**U_{sg}** ($g{\cdot}ml^{-1}$)	U/O Pre game (ml)	U/O During + end game (ml)

Appendix K: Match food record.

Match Food and Fluid Recording DATE……………… Location/Venue……………………...

Name / ID:……………………………………

Food + Fluid Type	Photo taken (Y/N)	Quantity / amount Kcals (*if known*)	Consumed (Y/N)	Amount consumed	Comments

Appendix L: Regional monthly climate averages for Auckland and Whangarei.

NIWA national data climate data base: Regional 30 year monthly average			
Month	Region	maximum daily temperature (°C) *	daily humidity (%) *
Nov	Whangarei	20.6	76.7±3
Nov	Auckland	19.5	76.6±3
Dec	Auckland	21.8	77.0±3
Jan	Whangarei	24.3	79.5±4

Calculated from the mean 30 year maximum average regional temperature National Institute of Water ad Atmospheric Research (NIWA). 2016. Available: http://www.niwa.co.nz/education-and-training/schools/resources/climate.

Appendix M: Game Characteristics - playing times and overs in key positions.

Game	Case	1st Key position	2nd Key position	1st Inn	2nd Inn	Innings played	Bowling overs	W/K overs/ Time (m)	Batting time (m)	Total Fielding Innings time (m)	Total Game time (m)	Comments
1	**1**	Pace		F	B	2	6		20	175	195	
1	**2**	5th Bat		F	B	2			20	175	195	
1	**3**	Pace		F	B	2	9		10	175	185	
1	**4***	Bat (1st)		F	B	2			20	175	195	
1	**5***	Bat (4th)		F	B	2			15	175	190	
1	**6**	Pace		F	B	1	7		0	175	175	12th Batter
1	**7**	Pace		F	B	2	9		29	175	204	
1	**8**	Wkt	3rd Bat	F	B	2		50/175	11	175	186	
1	**9**	Spin		F	B	2	10		49	175	224	
2	**10**	3rd Bat		B	F	2			77	204	281	
3	**11**	Bat (3rd)	Wkt	F	B	2		29/121	31	181	212	
3	**12**	Pace		F	B	1	9		0	181	181	12th Batter
4	**13**	Bat (1st)	Wkt	B	F	2		36.2/82	70	143	213	
5	**14**	Bat (3rd)		B	F	2			145	75	220	GEE
5	**15**	Pace		B	F	1	5		0	75	75	12th Batter, GEE
5	**16**	Pace		B	F	2	5		8	75	83	GEE
5	**17**	Field		B	F	2			20	75	95	GEE
5	**18**	Wkt		B	F	2		10/75	10	75	85	GEE
5	**19**	Spin		B	F	2	0		5	75	80	GEE
5	**20**	Pace		B	F	2	0		30	75	105	Injury pulled out of 2nd innings
5	**21**	Bat (4th)		B	F	1			3	75	78	GEE
5	**22**	Wkt		B	F	2		0	52	75	127	GEE
6	**23**	Bat (1st)		F	B	2			44	188	232	
6	**24**	Pace		F	B	6	5.5		16	188	204	
6	**25**	Spin		F	B	2	2		42	188	230	
6	**26**	Pace		F	B	2	9		3	188	191	
6	**27**	Bat (4th)		F	B	2			41	188	229	
						Totals		125.2/452	771	3899	4670	

* = GPS data not available, **B =** Batting innings, **Bat** = batter, **F** = fielding innings, **GEE** = weather disrupted - game ended early =did not perform role, **Inn** = innings, **m** = minutes, **Pace** = pace bowler, **Spin** = spin bowler, **W/K** = wicketing keeping, **Wkt** = wicket keeper

Appendix N: Pre-match data table (n=27).

Case	Game	H/A	Key position	Time	Place	Warm up Start time	Dietary intake on match day morning (on waking)	Drinks	Usg (g·ml-1)	Fluid rec	Fluid (ml)	EI (kJ)
1*	**1**	A	Pace	0830	Car	1005		Water.	1.060	330	750	0
2*	**1**	A	5th Bat	0630 0730	Hm Car	1005	W bagel, cream cheese, jam.	Coffee. Exp coffee (T/O).	1.020	366	500	2346
3*	**1**	A	Pace	0558	Hm	1005	ND cereal, milk.	Water.	1.027	419	437	1391
4*	**1**	A	Bat (1st)	0645	Hm	1005	Gr toast x 2, pan-fried sausages x 2, mayonnaise.	Water.	1.028	368	250	3165
5*	**1**	A	Bat (4th)	0322 0700	Hm Cafe	1005 post cycling	ND cereal, milk. Gr Toast x 1, poached egg x 2, hash brown x 2.	Milk, water. Exp coffee (café).	1.028	464	790	4788
6*	**1**	A	Pace 12th Bat	0650	Hm	1005	ND cereal, milk, W toast x 2, butter, marmite	Protein milk drink, fruit drink.	1.022	340	650	3917
7*	**1**	A	Pace	0700	Café	1005 post cycling	W toast x 1, pan-fried sausage x 1 ½, poached egg x 2, hash brown x 2.	Exp Mocha x 1. Water .	1.020	399	950	4778
8*	**1**	A	3rd Bat + Wkt	0645	Hm	1005	Gr Toast x 4, butter, marmite.	Water.	1.025	352	750	1578
9*	**1**	A	Spin	0630 0830	Hm Car	1005	W toast x 2, (no spread), poached egg x 2, banana x 2	Water.	1.024	310	500	2361
10*	**2**	H	3rd Bat	0715 0815	Hm	1000	Smoothie: oats, water, milk, canned peaches, strawberries, yoghurt.	Water + see smoothie. More water.	1.011	409	2662	1708
11*	**3**	H	Bat (3rd) + Wkt	0910	Hm	1003	Bacon, egg x 2 pan fried, W toast x 2, margarine, tomato sauce. Smoothie: banana, egg, yoghurt, raspberries, milk.	Water + see smoothie.	1.022	416	1000	4340
12*	**3**	H	Pace 12th bat	0900 0930	Hm Car	1003	Gr toast x 2, scrambled eggs (no fat) x 3.	Milk. Exp mocha (T/O)	1.060	444	1965	2367
13	**4**	H	Bat (1st) + Wkt	0810	Hm	0930	Bacon, egg x 2 pan fried, toast x 2, margarine, tomato sauce. Smoothie: banana, egg, yoghurt, blueberries, milk.	See smoothie.	1.022	416	250	5040
14*	**5**	H	Bat (3rd)	0800	Hm	0932		Milk protein drink.	1.028	377	250	932

15*	**5**	H	Pace 12th bat	0600	Hm	0932	Smoothie: milk, eggs x 3, sugar, vanilla essence.	See smoothie.	1.023	341	250	1407
16*	**5**	H	Pace	0725	Hm	0932	ND muesli, milk.	Vit B effervescent	1.023	347	500	2117
17*	**5**	H	Bat (1st)	0740	Hm	0932	ND muesli, milk, roasted almonds, banana	Water.	1.028	415	800	4146
18*	**5**	H	Wkt	0800	Hm	0932	Gr toast x 2, avocado.	Protein milk drink.	1.017	370	250	2607
19*	**5**	H	Spin	0730	Hm	0932	ND cereal, milk, poached egg x 1, Gr toast x 1.		1.026	381	187	1346
20	**5**	H	Pace	0700	Hm	0932	ND cereal, milk.	Water.	1.023	419	850	1480
21	**5**	H	Bat (4th)	0645 0700	Hm	0932	Raw almonds (handful).	Vit B effervescent. Protein milk drink.	1.032	465	550	1493
22	**5**	H	Wkt	0730	Hm	0932	ND cereal, milk, toasts x 2, margarine, marmite.		1.023	352	250	2273
23	**6**	A	Bat (1st)	0700	Hm	1002	W toast x 2, pan-fried sausages x 2, mayonnaise.	Water.	1.031	368	500	3072
24	**6**	A	Pace	0630	Hm	1002	ND muesli, milk, yoghurt.	Sports drink.	1.027	347	290	2371
25	**6**	A	Spin	0630	Hm	1002	ND cereal, milk.		1.031	381	125	527
26	**6**	A	Pace	0615	Hm	1002	ND cereal, milk.	Water.	1.025	418	500	1232
27	**6**	A	Bat (4th)	0630	Hm	1002		Vit B effervescent. P/P + milk shake	1.032	465	400	1106

Key: *n=18 = first occurring pre-match diet record, Same colours rows are the same participant.

12th bat = 12th batsman plays one innings, **A** = away game **Bat** = batter, **EI** = energy intake, **Exp** = a purchased espresso machine coffee, **Fluid Rec** = suggested minimum pre-match fluid recommendation based on 5ml / kg, **Gr** = grainy bread, **H** = home game, **Hm =** home**, Pace** = pace bowler, **PP** = protein powder, **Spin** = spin bowler, **T/O** = purchased as a take out, **Vit B** = vitamin B, **W** = refined white bread variety, **ND** = nutrient dense, moderate-low sugar cereal, **Wkt** = wicket keeper

Appendix O: Pre-match diet macronutrient intake in grams and as a percentage of total pre-match energy (n=18).

No.	Carbohydrate (g)	Protein (g)	Fat (g)	Carbohydrate (%)	Protein (%)	Fat (%)
1	0	0	0	0	0	0
2	61	18	27	43.6	12.9	43.5
3	55	11	7	67.3	13.5	19.3
4	35	58	23	24.2	40.1	35.8
5	124	51	48	43.8	18.0	38.2
6	145	31	17	67.7	14.5	17.9
7	75	39	76	26.3	13.7	60.0
8	56	12	10	61.9	13.3	24.9
9	95	20	10	69.1	14.5	16.4
10	62	16	9	63.1	16.3	20.6
11	88	54	51	34.3	21.0	44.7
12	54	50	16	38.6	35.7	25.7
13	30	15	4	55.6	27.8	16.7
14	21	28	16	24.7	32.9	42.4
15	72	18	15	58.2	14.5	27.3
16	114	30	143	47.4	12.5	40.2
17	59	26	30	38.7	17.0	44.3
18	35	19	11	44.4	24.1	31.4
Mean ± SD	65.6±37.1	27.6±16.6	23±19.8	44.9± 18.7	19.0±9.8	30.5±14.4
Median (25th-75th quartiles)	60 (35-88)	23 (16-39)	16 (10-30)	44.1 (34.3-61.9)	15.4 (13.5-24.1)	29.4 (19.3-42.4)

Pre match = before the competition and after 10pm the night before/breakfast

Appendix P: Pre-match carbohydrate intake (g) in relation to pre-event carbohydrate guidelines (n=18).

Participant No.	Actual intake of CHO (g)	Calculated at 1 g·kg^{-1}	Calculated at 2 g·kg^{-1}	Calculated at 3 g·kg^{-1}
1	0	76	147	228
2	61	73	167	220
3	55	84	147	251
4	35	74	186	221
5	124	93	136	279
6	145	68	159	204
7	75	80	141	239
8	56	70	124	211
9	95	62	163	186
10	62	82	166	245
11	88	83	178	249
12	54	89	166	266
13	30	75	136	226
14	21	68	139	205
15	72	69	166	208
16	114	83	148	249
17	59	74	152	222
18	35	76	167	229
Percentage meet		N=6 33.3%	N=0 0.0%	N=0 0.0%

Appendix Q: Match venue, facilities and catering provisions.

Game	Location	Facilities	Water Supplied by Host team	Food Supplied	Food Service
1	Whangarei (away) Kensington Oval	No facilities. Empty water bottles refilled from public toilet tap water.	Bottled water (inadequate supply). Research team labeled & refilled empty bottles from public toilet tap water.	Protein salad filled rolls (mini platter size portions) Protein fillings included: sandwich meats, tuna, cheese.	Franchise caterer Delivered to field. Players collected in a structured manner, consumed lunch outdoors.
2	Auckland (home) Melville Park	Basic club room including kitchen, medium sized dining room, basic tables, insufficient tables and chairs for all to sit at. Change rooms, with toilets and outdoor shelter.	Plentiful chilled water bottles provided, labeled, replaced.	Allocated per player: medium sized sweet muffin, medium banana & white filled roll (round bap) with ice-burg lettuce leaf, processed sandwich ham (30g), grated cheddar cheese (15g), mayonnaise (thinly spread), 1 slice tomato.	Independent catering. Delivered to club rooms. Option to sit indoors or outside, most players consumed lunch together inside the changing rooms.
3	Auckland (home) Melville Park			Allocated per player: medium sized sweet muffin, lamington, a cheese top white long bread roll (70g) filled with ice-berg lettuce leaves, roasted chicken breast meat (40g), grated cheddar cheese (~20g), sweet chilli sauce (1 tsp) & multigrain bread bacon (40g) egg x 1 (fried in vegetable oil) sandwich.	
4	Auckland (home) Melville Park			Plentiful supply per player Medium sized sweet muffins & **extra large** long white rolls (150g bread weight) filled with ice-berg lettuce leaves, roasted chicken or beef (150g), grated cheddar cheese (60g), tomato 3 slices, mayonnaise (2 Tbsp).	
5	Auckland (home) Cornwall Park	Club room including fully functional kitchen, large dinning room, change rooms with toilets, extra toilets off dining room and outdoor shelter.	Sponsors provided empty drinking bottle vessels. Large cooled water provisions provided. Bottles labeled and refilled.	Beef, chicken & vegetarian lasagna, bananas, strawberries, mayonnaise based salads: coleslaw, potato & egg curry, garden salad: ice-burg lettuce, carrot, tomato, cucumber and red pepper, red onion salad, beetroot slices, store brought "light" salad dressing, bacon cheesy breads	Catering prepared and cooked from fresh on site. Self service. Option to sit indoors or outside, all players consumed lunch in dining room.
6	Whangarei (away) Cohham Oval	Club room including fully functional kitchen, large dinning room, change rooms with toilets, extra toilets off dinning room and outdoor shelter.	Plentiful chilled water bottles provided, labeled, replaced.	Lasagna – beef or chicken, bananas, fresh pineapple & melon, sliced cooked meats – beef roast & ham, roasted potatoes, bread – white soft baps, roast tomato chutney, peas, beans, citrus & kumara sour cream mayonnaise salad, garden salad: mesclun, carrot, cherry tomatoes, avocado, cucumber, red onion.	Catering prepared and cooked from fresh on site. Self service. Option to sit indoors or outside, all players consumed lunch in dining room.

Appendix R: Dietary match intake.

Game	Case	Extra snacks & beverages	Snacks consumed	Lunch consumed	Beverages consumed (Additional to water)
1	1	Banana x 2 & Apple x 1 Jam & peanut butter sandwich	Banana Jam & peanut butter sandwich	2 x small protein / salad bread roll: chicken / turkey	
1	2	Apple x 1 Crackers 50g & cheese 60g Bacon & egg sandwich Oat slice muesli bar (25g) Almonds (2 handfuls) Protein milk drink (60ml)	Almonds (handful)	3 x small protein / salad bread roll: beef / turkey	Protein milk drink - chilled product (600ml)
1	3	NIL		2 x small protein / salad bread roll: chicken	
1	4	Banana x 2 & mandarin x 2 Cucumber slices (1/4 cup) Hard boiled egg x 4 Chicken patty in a white burger bun	Banana x 1 Cucumber (5 slices)	3 x small protein / salad bread roll: cheese / vegetarian	
1	5	NIL		2 x small protein / salad bread roll: chicken / cheese vegetarian	
1	6	Sports drink (1500ml)		2 x small protein / salad bread roll: chicken / turkey	Sports drink (1100ml)
1	7	Sports drink (750ml)		2 x small protein / salad bread roll: chicken / salami	Sports drink (375ml)
1	8	Banana & apple Muesli bars Flemings x 2	½ banana Muesli bar x 2	2 x small protein / salad bread roll: beef	
1	9	Sports drink (750ml). Filled roll large (purchased from franchise store).	Large filled roll chicken / salad purchased from same lunch franchise provider	3 x small protein / salad bread roll: chicken / beef / turkey	Sports drink (500ml)
2	10	Banana x 2 Chocolate muffin Chocolate covered snack bar Sports drink (750ml)	Banana x 2 Supermarket bakery chocolate muffin	1 x medium protein / salad bread roll: ham/cheese + banana + chocolate muffin	Sports drink (750ml)
3	11	NIL	½ banana*	Bacon + egg sandwich + medium protein / salad roll: chicken + lamington + chocolate muffin	

3	**12**	NIL	½ Banana*	Bacon + egg sandwich + medium protein / salad roll: chicken + lamington + blueberry muffin + banana	
4	**13**	Banana Roasted almonds (2 handfuls) Sports drink (750ml)	Banana x 1	1 + ¾ extra large protein / salad roll: beef / cheese	Sports drink (750ml)
5	**14**	NIL	Banana*	Chicken lasagna + extra chicken + potato salad, egg curry salad + bacon cheesy bread	
5	**15**	Nut bar yoghurt coated (25g) Processed cheese & crackers Packet popcorn (12g)	Nut bar Processed cheese & crackers Packet popcorn Banana x 2*	Beef lasagna +potato salad + beetroot + bacon cheesy bread	
5	**16**	Baked beans 220g x 2 Sports drink (750ml)	Baked beans (440g) Banana (small)*	Beef lasagna + ½ vegetarian lasagna + beetroot + egg curry salad bacon cheesy bread x 1 ½ + strawberries	Sports drink (750ml)
5	**17**	Tuna snacks (95g x 2)	Tuna & crackers (185g) Banana (small) x 3*	Beef lasagna + strawberries + coleslaw + potato salad + egg curry salad + garden salad + bacon cheesy bread x 2	
5	**18**	NIL		Meal from home: bacon and vegetable brown rice salad + potato salad	
5	**19**	Croissant (small) Mandarin Pretzels (28g) Sports drink (750ml) Protein milk drink (250ml)	Croissant (small) Banana (small) x 2*	Beef lasagna + potato salad + egg curry salad + bacon cheesy bread x 2	Protein milk drink -UHT box. (250ml) Sports drink (50ml)
5	**20**	Sports drink (750ml)		Beef lasagna + strawberries + bacon cheesy bread x 2	Sports drink (750ml)
5	**21**	Sports drink (750ml)	Banana x 3(small)*	Chicken lasagna + 1/3rd vegetarian lasagna + garden salad + bacon cheesy bread x 3	Sports drink (520ml)
5	**22**	Apple Crisps 33g muesli bars (30g x 2) cheesy bacon bread (150g)	Apple Crisps 33g Muesli bar x 2 Cheesy bacon bread x 2	Beef lasagna + garden salad + bacon cheesy bread x 2	
6	**23**	Boiled eggs x 5 Chicken patty in a white burger bun		Bite sized amount of roasted potatoes + citrus & kumara sour cream mayonnaise salad + garden salad	
6	**24**	Sports drink (750ml)	Bananas x 3 (small)*	½ serve beef lasagna + pineapple + melon + slices of beef roast & ham + roasted potatoes + bread – white soft bap + roast tomato chutney, + peas + beans + citrus & kumara	Sports drink (750ml)

				sour cream mayonnaise salad + garden salad	
6	**25**	Banana Packet popcorn (12g) Banana bread (60g) Protein milk drink (250ml) Sports drink (750ml)	Banana Banana bread 30g	Beef lasagna + bread – white soft bap + small serve of pineapple, roasted potatoes	Sports drink (225ml)
6	**26**	NIL	Banana (small)*	1 ½ serves beef lasagna + bread – white soft bap x 2+ pineapple + melon + ham + roasted potatoes	
6	**27**	Sports drink (2250ml)	Banana (small)*	1 ½ serves beef lasagna +pineapple + slices beef roast + roasted potatoes + citrus & kumara sour cream mayonnaise salad, + garden salad	Sports drink (2250ml)

*bananas that were provided by the coach

Appendix S: Match macronutrient intake (n=27).

Cases	Match			
No.	Carbohydrate (g)	carbohydrate ($g.h^{-1}$)	Protein (g)	Fat (g)
1	141	33	48	22
2	132	31	85	55
3	52	13	36	13
4	88	21	28	25
5	72	17	40	21
6	75	19	31	14
7	73	17	42	29
8	100	24	36	30
9	154	33	89	32
10	196	34	20	27
11	147	32	46	58
12	209	52	53	62
13	210	46	62	38
14	95	20	50	45
15	147	65	51	54
16	187	78	71	41
17	85	33	89	54
18	133	55	31	38
19	161	69	71	58
20	122	44	46	33
21	175	77	59	42
22	157	50	64	67
23	14	3	3	7
24	187	43	36	25
25	124	26	39	30
26	129	31	45	28
27	203	42	58	47
Means ± SD	129±50	35±20	49±21	36±16
Median (25th-75th quartiles)	133(88-161)	33(20-46)	46(36-62)	33(25-47)

Match = warm-up + game.

Appendix T: Match carbohydrate intake (g) in relation to carbohydrate event guidelines (n=27).

Cases	Case CHO intake per hour	Case CHO intake in total	Calculated recommended ranges for CHO intake *		
No.	CHOg.h-1	Match total CHO(g)	30 g.h-1	60 g.h-1	90 g.h-1
1	33	141	128	255	383
2	31	132	128	255	383
3	13	52	122	245	367
4	21	88	128	255	383
5	17	72	125	250	375
6	19	75	118	235	353
7	17	73	132	264	396
8	24	100	123	246	369
9	33	154	142	284	426
10	34	196	170	341	511
11	32	147	136	271	407
12	52	209	120	240	360
13	46	210	137	273	410
14	20	95	140	280	420
15	65	147	68	135	203
16	78	187	71	143	214
17	33	85	77	155	232
18	55	133	73	145	218
19	69	161	70	140	210
20	44	122	83	165	248
21	77	175	68	137	205
22	50	157	94	187	281
23	3	14	146	292	438
24	43	187	132	264	396
25	26	124	145	290	435
26	31	129	125	251	376
27	42	203	145	289	434
Number met Percentage met			17 63.0 %	3 11.1%	0 0.0%

Key: CHO = carbohydrate, **g.h-1**= grams per hour
*** (Burke *et al.*, 2011), (Thomas *et al.*, 2016)**

Appendix U: Match and total dietary intake: macronutrient composition as a percentage, (n=27).

Cases	Match dietary intake **(%)**			Total dietary intake **(%)**		
No.	% Carbohydrate	% Protein	% Fat	% Carbohydrate	% Protein	% Fat
1	59.1	20.1	20.8	59.1	20.1	20.8
2	38.7	24.9	36.3	40.2	21.4	38.4
3	44.3	30.7	24.9	53.8	23.6	22.6
4	51.1	16.3	32.7	38.8	27.1	34.1
5	45.2	25.1	29.7	44.3	20.6	35.1
6	54.5	22.5	22.9	62.5	17.6	19.8
7	40.5	23.3	36.2	31.8	17.4	50.8
8	49.1	17.7	33.2	53.1	16.3	30.6
9	48.9	28.3	22.9	55.0	24.1	20.9
10	70.8	7.2	22.0	68.8	9.6	21.6
11	45.4	14.2	40.3	40.5	17.2	42.3
12	52.1	13.2	34.7	48.6	19.0	32.4
13	58.7	17.3	23.9	49.2	19.6	31.2
14	38.6	20.3	41.1	41.6	21.6	36.7
15	46.0	16.0	38.0	41.5	19.5	38.9
16	53.4	20.3	26.3	54.6	18.8	26.6
17	28.8	30.1	41.1	37.1	22.2	40.7
18	53.3	12.4	34.3	47.8	14.2	38.1
19	44.4	19.6	36.0	44.4	20.4	35.2
20	50.4	19.0	30.7	53.4	20.6	25.9
21	53.3	18.0	28.8	49.7	19.0	31.3
22	42.2	17.2	40.6	44.2	17.0	38.8
23	42.7	9.2	48.1	25.0	11.6	63.5
24	67.0	12.9	20.1	64.5	14.4	21.1
25	53.8	16.9	29.3	53.2	17.6	29.3
26	54.4	19.0	26.6	57.1	20.3	22.5
27	57.2	15.2	27.6	50.6	22.9	26.5
Mean ± SD	49.8±8.9	18.7±5.8	31.4±7.4	48.5±10	19±3.8	32.4±10
Median (25th-75th quartiles)	50.4(44.3-54.4)	10.0(15.2-22.5)	30.7(24.9-36.3)	49.2(41.5-54.6)	19.5(17.2-21.4)	31.3(22.6-38.4)

Match dietary intake (%) = nutrient intakes from warm-up + match time. **Total dietary intake (%) =** nutrient intakes from Pre-Match, warm-up + match time.

Appendix V: Movement category distance by playing position in one-day cricket matches (mean±SD).

Activity	Number	Distance covered (metres/hour)				
		Walking 0-2·00 $m \cdot s^{-1}$	Jogging 2·01-3·50 $m \cdot s^{-1}$	Running 3·51-4·00 $m \cdot s^{-1}$	Striding 4·01-5·00 $m \cdot s^{-1}$	Sprinting ≥5·01 $m \cdot s^{-1}$
Batting	36	1808±400	279±119	86±37	154±70	149±94
Fast bowling	24	2520±362	618±217	157±58	220±81	316±121
Fielding	52	2117±374	640±193	119±46	124±59	81±51
Spin bowling	8	2251±239	621±154	116±43	120±63	58±37
Wicket keeping	6	1913±196	558±104	109±16	97±29	34±21

Table replicated from C. J Peterson et al. (Petersen *et al.*, 2010)