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The sweating response, body weight changes and coluntary fluid intakes during training and competition of fast bowlers: A case study

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The Sweating Response, Body Weight Changes and Voluntary Fluid Intakes During
Training and Competition of Fast Bowlers: A Case Study

“Dissertation submitted in accordance with the requirements of University of
Chester for the degree of Master of Science.”

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Abstract

J.W. Bray, The Sweating Response, Body Weight Changes and Voluntary Fluid Intakes During Training and Competition of Fast Bowlers: A Case Study.

The aim of this study was to examine heart rate, sweat rate and composition, as well as urinary volume, colour and osmolarity, during a single competitive cricket match and training session. Two sub-elite fast bowlers (age, 20.5 ± 0.71 years; height, 178 ± 1.41 cm; body mass, 75.5 ± 0.71 kg; mean \pm standard deviation) participated in this study. Subjects were measured under warm environmental conditions with wet bulb globe temperature indices of 22.9 and 19.5, respectively. Heart rate was recorded continuously throughout the match and the training session using Polar Vantage NV recordable heart rate monitors. Both players were weighed before and after each session of play and during competition and training. Absorbent patches collected sweat from the upper back and forearm. These remained in place for the duration of competition and training. Sweat was subsequently analysed for sodium (Na^+) and potassium (K^+) composition. Throughout the periods of data collection urine was collected and measured for volume, colour and subsequent osmolarity. Average heart rates for competition were 115 ± 25 and 109 ± 22 $\text{beats}\cdot\text{min}^{-1}$ and training 134 ± 29 $\text{beats}\cdot\text{min}^{-1}$, respectively. Body mass loss during training for both subjects was 0.5 kg, equivalent to dehydration of 0.67 and 0.66% of pre-training body mass. The sweat volume lost during competition was 0.73 and 0.93 $\text{L}\cdot\text{hr}^{-1}$. The Na^+ composition of the sweat from competition was 27.3 ± 14.8 and from training 41.2 ± 6.3 $\text{mmol}\cdot\text{l}^{-1}$, respectively. The K^+ composition of the sweat from competition was 2.85 ± 1.1 and from training was 2.35 ± 0.2 $\text{mmol}\cdot\text{l}^{-1}$, respectively. The results from this study identify the inter-differences in both sweating response and drinking practices of the two fast bowlers, thus supporting the use of individualised hydration strategies.

Key words

Cricket, fast bowling, dehydration, sweating

This work is original and has not been previously
submitted in support of a Degree, qualification or
other course.

Signed

Date

Contents	Page Number
Acknowledgements	i
Abstract	ii
Declaration	iii-iv
Chapter 1: Introduction	1 – 7
Chapter 2: Literature review	8
Chapter 2.1: Cricket specific literature	8 – 20
Chapter 2.2: Team sport literature	20 – 24
Chapter 2.3: Hydration testing literature	24 – 42
Chapter 3: Method	43 – 51
<ul style="list-style-type: none"> • Subjects • Preliminary testing • The match • The training session • Experimental design • Sweat rate, Urine sampling, Sweat composition and Heart Rate for both competition and training • Data analysis 	43 44 44 45 46 48 51
Chapter 4: Results	52 – 62
<ul style="list-style-type: none"> • Environmental conditions • Competition heart rates • Training heart rates • Competition sweat rates and fluid replacement • Training sweat rates • Competition urinary volume, colour and osmolality • Training urinary volume and osmolality • Competition sweat composition • Training sweat composition 	52 52 55 56 57 59 61 61 62

Chapter 5: Discussion	63 – 71
• Environmental conditions	63
• Heart rate	64
• Sweat rate and fluid replacement	65
• Renal changes	68
• Sweat composition	69
• Research limitations and further research	70
• Conclusion	71
References	72 – 75
List of Appendices	ix

List of figures	Page Number
Figure 1. Schematic representation of methodology	48
Figure 2. Heart rate profile for Subject 1	53
Figure 3. Heart rate profile for Subject 2	54
Figure 4. Mean heart rates for competition, spell duration and training (subject 1)	55
Figure 5. Mean heart rates for competition, spell duration and training (subject 2)	56
Figure 6. Sweat rates for both subject 1 and 2 during both competition and training	58
Figure 7. Urine osmolality at each scheduled break in play during competition (subject 1)	59
Figure 8. Urine osmolality at each scheduled break in play during competition (subject 2)	60

List of tables	Page Number
Table 1. Subject characteristics	43
Table 2. Environmental conditions during competition and training	52
Table 3. Sweat sodium and potassium concentrations for each subject during both competition and training	62

List of Appendices	Page Number
Appendix I – First study to examine urinary indices of hydration status.	76 - 78
Appendix II – Letter of approval for the experimental procedures obtained from the Centre for Public Health Research Ethics Committee of the University of Chester	79 - 80
Appendix III – Letter of recruitment to Somerset County Cricket Club	81
Appendix IV – Participant information sheet	82 - 84
Appendix V – Example consent form	85
Appendix VI – Example medical history questionnaire	86 - 87
Appendix VII – ECB playing regulations	88 - 96
Appendix VIII – Urine colour chart	97
Appendix IX – Bases code of conduct	98 - 102
Appendix X – Subject raw data	103 - 113

Chapter 1 – Introduction

In most countries, team sports have the highest levels of participation and the highest levels of growth (Burke & Hawley, 1997; Devlin, Fraser, Barras & Hawley, 2001). Cricket is no exception and is one of the oldest organised team sports (Noakes & Durandt, 2000). Cricket is played on an international stage by teams from Australia, Bangladesh, England, India, Ireland, Kenya, New Zealand, Pakistan, South Africa, Sri Lanka, West Indies and Zimbabwe (Gore, Bourdon, Woolford & Pederson, 1993; ICC, 2007).

Cricket, from a physiological perspective, is a prolonged, variable intensity team sport (Soo & Naughton, 2007). Players are required to perform multiple bouts of intermittent work at near maximal effort, punctuated with intervals of low intensity exercise or rest, for the duration of the match (Burke & Hawley, 1997; Shi & Gisolfi, 1998). Players are frequently required to sprint, accelerate and jump, therefore increasing exercise intensity and energy expenditure (Shi & Gisolfi, 1998). Cricket is characterised not only by an intermittent high-intensity workload but also by the contribution of skill and motor performance, and the importance of mental functioning that is needed to make tactical changes (Burke, 1997). These types of exercise can last anywhere from two to three and a half hours (ECB, 2007) depending on the type of match. During a “test match” there are no laws restricting the amount of overs bowled by a bowler, thus a bowler could bowl from the “start of play” (11:00) through to “lunch” two hours later. However there are restrictions in place when participating in “limited overs” cricket which prevent a bowler from bowling any more than ten overs (ECB, 2007). These activity patterns are associated with a significant loss of body water, which has a negative impact upon

physical and mental performance as well as temperature regulation (Burke & Hawley, 1997). Therefore, the maintenance of fluid balance is a key issue in the health and performance of the athlete (Burke, 2001).

Traditionally cricket is played over the summer season and as such, players may be required to practice or compete in hot (>25°C, 60% relative humidity) environments (Burke, 1997; Burke & Hawley, 1997; NATA, 2000). Therefore the concept of fluid balance is critical to ensure optimal performance. In hot environments, significant hypohydration is inevitable during many exercise activities due to increased fluid losses and poses a challenge to both the health and performance of the athlete (Burke, 2001). In cricket, the opportunity to ingest fluids during competition is governed by different factors and such opportunities vary according to the rules of the game (Burke, 1997). The international rules governing cricket (ICC, 2006) allow for an official drinks break every 40-60 minutes, although the law does allow for an individual player to receive a drink either on the boundary edge or at the fall of a wicket on the field provided that no playing time is wasted (ICC, 2006). Clearly such laws prevent adequate fluid replacement in hot conditions where sweat rates are high (Burke, 1997). These laws do not take into account the extreme environmental playing conditions and are therefore likely to be inadequate, particularly for fast/medium pace bowlers who are performing high intensity exercise with the associated need to disperse heat generated (Gore et al. 1993).

To provide an understanding of fluid intake strategies for exercise it is helpful to have a clear understanding of definitions related to fluid balance. An athlete with normal total body water is said to be in a state of euhydration, while having total body water below normal is defined as being in a state of hypohydration and this is achieved by the process known as dehydration (Burke, 2001).

Such hypohydration can occur because an athlete's sweat rate is extremely high, as there is little opportunity to drink during the event, or because both factors (high sweat rates and/or restricted fluid availability) are combined (Burke, 2001). In a hot environment the primary method of dissipating body heat produced by exercising muscles or absorbed from the environment is via the evaporation of sweat. This process will only occur when ambient temperature exceeds skin temperature, thus heat loss can occur only by evaporation of sweat from the skin surface (Shirreffs, Armstrong & Chevront, 2004). When sweating takes place, the free exchange of water among body fluid compartments ensures that the water content of sweat is derived from all compartments, with the distribution being influenced by sweat rate, sweat composition and total water and electrolyte loss (Shirreffs et al. 2004). The two main methods that have been used in assessing electrolyte loss through sweat involve either the collection of sweat from a specific body region using some form of absorptive patch or a variation on the whole body wash down technique (Shirreffs, Sawka & Stone, 2006). Typically the use of absorptive patches are preferred in the field as it is a relatively simple technique, although clubs and players are likely to need specialised help (Burke, 2005). Besides providing approximate sweat electrolyte losses, collecting sweat with an absorptive patch identifies those athletes with electrolyte rich sweat. Sodium is the primary cation lost in sweat, with typical concentrations of $\sim 40\text{-}60 \text{ mmol.l}^{-1}$ compared with $\sim 4\text{-}8 \text{ mmol.l}^{-1}$ for potassium (Shirreffs et al. 2004).

The metabolic heat generated by exercise must be dissipated to maintain body temperature within narrow physiological limits (Shirreffs et al. 2004). The impact of fluid loss on the body's homeostasis becomes of greater concern when the performance is required in a thermally stressful environment, as the magnitude of

physiological disturbance is directly related to the degree of dehydration (Devlin et al. 2001). The more pronounced the water deficit the greater the reduction in physical work capacity (Devlin et al. 2001).

Exercise performance is impaired when an individual is dehydrated by as little as 2% of body weight (Jeukendrup & Gleeson, 2004). Losses in excess of 5% of body weight can decrease the capacity for work by up to 30% (Devlin et al. 2001; Jeukendrup & Gleeson, 2004). With this in mind it has been recommended that the optimal rate for fluid replacement during prolonged exercise is the rate that most closely matches sweat loss, at least up to 80% of fluid replacement (Coyle & Montain, 1993). Research (Lind, 1963; Kraning & Gonzalez, 1991) conducted on intermittent exercise in hot environments is sparse with even fewer studies (Nevill, Garrett, Maxwell, Parsons & Norwitz, 1995) examining intermittent exercise with bursts of all-out sprinting in hot conditions. Fast bowlers may experience exercise rigors in similar conditions though few studies (Gore et al. 1993; Devlin et al. 2001) have looked specifically at the replacement of fluid. Despite the vast popularity of cricket and the large numbers participating, there has been very little research investigating the special nutritional needs of cricket players (Gore et al. 1993) during competition, even less research has been conducted on the simple issue of fluid requirements (Burke, 1997). Unfortunately for team sport players and more specifically fast bowlers, the majority of scientific attention has been focused upon the fluid, energy and electrolyte requirements of individuals participating in prolonged (≥ 90 minutes) continuous, moderate intensity ($< 75\%$ maximal oxygen uptake) exercise (Burke & Hawley, 1997), typically in locomotor sports such as running and cycling.

To date there is only one published research paper investigating the effects of fluid losses during competitive cricket (Gore et al. 1993). However more recently research (Devlin et al. 2001) has been produced to identify the consequences of dehydration and how it impacts bowling performance. Research by Gore and co-workers (1993) found that during a hot day (~32°C dry bulb) fast bowlers were unable to maintain good levels of hydration. In fact after only two sessions of play (2 x 2 hours) players lost an average of 4.3% of body mass. The findings from Gore and co-workers (1993) cited levels at 5% loss of body mass; the point at which it has been suggested a potential decline in performance by up to 30% may occur. Research conducted by Devlin and colleagues (2001) found that moderate levels of hypohydration (2.8% of body mass) significantly impaired bowling line ($P < 0.01$) and length ($P < 0.01$) respectively. These findings are in line with earlier findings from Gore et al. (1993) as a decline of ~16% was observed in bowling performance (line and length) when subjects were dehydrated by 2.8% of body mass, thus hypothesising that if levels encroached upon levels cited earlier of 5% then a 30% decline in performance could occur. The findings from these few studies add credence to the need for further research investigating the fluid requirements for fast bowlers.

Despite the capacity of the human body to dissipate the additional heat produced during exercise (Morris, Nevill, Lakomy, Nicholas & Williams, 1998) and the benefits of ingesting fluid to offset dehydration, exercise in the heat is associated with a gradual rise in core body temperature (from ~36° to 38°C at rest to $\geq 39^\circ\text{C}$, Jeukendrup & Gleeson, 2004), which will cause a premature onset of fatigue or reduced performance compared with performance in cooler conditions (Burke, 2001).

Exercise in a hot environment is associated with a shift in substrate utilisation towards a greater reliance on the body's carbohydrate (CHO) stores (Burke, 2001). This is of key significance as carbohydrates are the primary energy source during vigorous exercise (Boyadjiev & Tarulov, 1998). Together with there being a greater reliance on the body's CHO stores in hot environments, exercise intensity increasing the active muscles become more dependant upon CHO as a source of energy (Jeukendrup & Gleeson, 2004). This is of great importance for cricketers as the majority of competition will be in a hot environment and the activity pattern typically associated with fast bowling is of a high intensity. The availability of CHO as a substrate for skeletal muscle contraction and the central nervous system is important for the performance in high intensity exercise experienced by cricketers (Jeukendrup & Gleeson, 2004).

With a greater number of games being played, especially with the inclusion of the Twenty20 Cup in 2003, the demands placed upon the professional cricketer far exceed those of the past. In addition to more games within a season, the venues for international competitions and world championships are frequently in hot climates (Morris et al. 1998). A prime example of this was the 2007 ICC Cricket World Cup in the West Indies where temperatures regularly reached 32°C (Met Office, 2007). These conditions, are not typically conducive for optimal performance (Burke, 2001), especially for events such as fast bowling, which requires intermittent high intensity exercise. Therefore nutritional strategies play an integral role in assisting the athlete to perform as well as possible (Burke, 2001). As well as the basic nutritional demands placed on the athlete, additional special needs such as voluntary fluid intake are created from exercising in the heat.

With such a dramatic change-taking place within sport, research has not kept pace, as there still appears to be a lack of substantive research into nutritional and fluid intake needs of fast bowlers. Therefore the primary purpose of this study is to identify individual sweat rate, heart rate, urinary volume and osmolarity as well as electrolyte concentrations in sweat during a single competitive match and training session, and to relate these measures to the thermal environment and activity levels of fast bowlers. A secondary aim was to determine if the recommendations providing guidelines for optimal practices in team sports (Burke, 1997; Burke & Hawley, 1997) and position statements for fluid replacement (ACSM, 1997; NATA, 2000) will aid in maintaining adequate levels of hydration for optimal performance.

Chapter 2 – Literature Review

This literature review will draw on published material from current to early scientific research papers. Unfortunately the physiological (Noakes & Durandt, 2000) and nutritional (Gore et al. 1993; Devlin et al. 2001) demands of the game of cricket, in particular fast bowling have not been extensively researched. Therefore this review will draw on material on cricket, team sports and hydration monitoring. Published science, medicine and nutrition journals across the world will provide the scientific background of this study, coaching reports and publications that have applications to the hydration for fast bowlers will also be included and reviewed.

Chapter 2.1 – Cricket Specific Literature

Research conducted by Noakes and Durandt (2000) investigated the physiological requirements of cricket. The authors identify that cricket is undergoing a phase of rapid change as it competes to attract a more global audience. As a result, modern cricketers are now exposed to greater physical demands (Noakes & Durandt, 2000). Now expected to perform under these conditions, it is suggested (Noakes & Durandt, 2000) that only the best prepared cricketers will perform better, more consistently, with fewer injuries thus resulting in a longer playing career. With this in mind the researchers aim was to understand better the physiological demands of modern cricket for the benefit of individual players and teams.

Although many exercise physiologists have yet to embrace the physiological demands placed upon an elite cricket player it is suggested (Noakes & Durandt, 2000) that there are four physiological factors that limit performance; the classic

cardiovascular-anaerobic model (Noakes & Durandt, 2000), the energy supply-energy depletion model (Noakes & Durandt, 2000), the muscle power-muscle recruitment model (Noakes & Durandt, 2000) and the biomechanical model (Noakes & Durandt, 2000). These models were all used by Noakes & Durandt (2000) to further evaluate the physiological factors that determine physical performance in cricket. The authors suggest that modern cricketers will benefit from superior physical fitness, regardless of skill. Therefore for cricketers of equal skill, physiological factors determining fitness will ultimately predict success and longevity in cricket.

From a physiological viewpoint none of the previously mentioned traditional models used for athletes can be used to explain exercise fatigue in cricket. All of these models suggest that cricketers should be able to play without fatigue, although there is no data to support this. It is commonly believed that bowling speed and accuracy decline after 6-8 overs of fast bowling. Although slightly more recent research (Devlin et al. 2001) suggests that bowling accuracy declines where as speed does not. It is clear however that cricketers suffer from fatigue, both mentally and physically. Thus posing the question why do cricketers need to be fit? For this to be answered the authors analysed the demands of one-day cricket. An estimate of the physical activity required for fast bowling during one-day cricket suggests that fast bowlers deliver ~64 deliveries (60 legal and 4 wides/no balls) in forty minutes. During this time bowlers are expected to run 1.9 km in about 5.3 minutes at an average speed of $21.6\text{km}\cdot\text{h}^{-1}$. When viewed in this context, it is apparent that the demands of bowling in one-day cricket are substantial (Noakes & Durandt, 2000). It is clear that elite players in particular need to be athletic to be able to reproduce

these performances frequently, especially during a series of one-day international matches, in which cricketers participate in 3.5 hours of intense fielding.

Through professional consultations the authors were able to aid in the physical preparation of both the South African cricket and rugby teams and subsequently compared the physiological characteristics. The data from this comparison showed that there was no real physiological difference between these groups ($\text{VO}_{2\text{max}}$ and body fat %; cricket $\sim 58 \text{ ml.kg.min}^{-1}$ and $\sim 13\%$ body fat vs. rugby $\sim 56 \text{ ml.kg.min}^{-1}$ and $\sim 12\%$ body fat, respectively) despite the much greater demands of rugby. The South African cricketers assessed were as fit as international rugby players, suggesting that, cricket is far more demanding physiologically than previously recognised (Noakes & Durandt, 2000). In conclusion the results presented in this study show that unfortunately little is still known about the physiological requirements of cricket, although elite cricketers do possess high levels of fitness.

Research conducted by Gore and colleagues (1993) investigated involuntary dehydration during cricket. The authors start by highlighting that the international rules governing cricket do not take in to account of the extreme environmental conditions under which the game is played. Unfortunately for cricketers competing when ambient shade temperatures exceed 40°C the opportunity to rehydrate is restricted to every 40 minutes. This is likely to be inadequate especially for fast/medium pace bowlers who are performing at a high intensity (Gore et al. 1993). Given this limited opportunity to replenish fluid losses during cricket the authors suggest that skill levels and therefore performance would diminish as dehydration increases beyond $\sim 2\%$ of initial body mass. With this in mind the purpose of this study was to measure sweat rate, heart rate, rectal temperature, urinary volume and

electrolyte concentrations during actual and simulated cricket matches. A secondary aim was to determine if the current rules provided sufficient opportunities for the maintenance of adequate hydration.

Twenty male first-grade cricketers (8 batsmen and 12 bowlers) were recruited to take part in this study. Subjects were tested under three environmental conditions (hot $\geq 38^{\circ}\text{C}$, warm $\sim 30^{\circ}\text{C}$ and cool 22°C) to determine sweat rates. A repeated measures design was conducted on the bowlers ($n = 12$) over three cricket seasons to obtain measurements for cool, warm and hot conditions. Prior to any analysis subjects completed two habituation sessions. Three bowlers were measured under actual match conditions in weather that approximated a hot day, with thirteen completing the cool match simulation and eleven completing the warm match simulation. Simulated matches were used to approximate actual match conditions as during the actual match limited data was collected, as some bowlers were not given the opportunity to bowl because of tactical decisions. Seven players completed both cool and warm match simulations with measurements on the hot day only lasting until the tea break because the opposition was bowled out.

For each day of simulated play, three practice nets were used, with two bowlers and two batsmen assigned to each net. All subjects were required to wear full cricket whites. Work rates were chosen for the simulated matches to approximate the upper range of that which occurs during a match. This equates to each bowler delivering a total of 28 overs in the form of a total of twelve overs in the first session, 6 overs in the second session and a 10 over spell bowled in the third session. Water was available to subjects as per normal match conditions, that is ad libitum pre-match and during the lunch and tea breaks. Body mass was determined clothed at the beginning and end of lunch breaks as well as nude pre and post match. Fluid intake

and output was measured with a 5ml urine sample collected and stored prior to analysis of electrolytes, osmolality and pH. Sweat rates were estimated from a fluid balance profile as the change in body mass over time.

The data collected from sweat rates, drink volumes, urinary volume, osmolality, Na^+ , K^+ , pH and heart rate measured during each session was analysed using General Linear Modelling. Analysis of variance was conducted for each variable with the following terms in the model: day (cool, warm and hot), time (of day) and player (bowlers). Adjusted Bonferroni t-tests were used to identify significant differences.

The main findings from this study was that there was a significant day main effect for sweat rate ($P = 0.002$) with the rate on the cool day ($0.54 \pm 0.03 \text{ kg}\cdot\text{hr}^{-1}$) being significantly lower than the rate on the hot day ($1.37 \pm 0.06 \text{ kg}\cdot\text{hr}^{-1}$). After completion of the first session during the hot day bowlers were dehydrated ($-3.8 \pm 0.5\%$ of initial body mass) despite consuming on average 0.56 litres in the first hour drink break and 0.52 litres in the second hour drinks break. During the second session of play, two more drinks breaks were taken with the average total volume consumed 0.60 litres. At the end of this session of play, when the opposition were dismissed the average level of dehydration was $-4.3 \pm 0.7\%$ of initial body mass.

In conclusion, the authors highlight that after only two sessions of play the average level of dehydration in hot conditions was -4.3% of initial body mass. This level of dehydration is sufficient to impair physical performance and there is an increase potential for heat illness. It is also suggested that if the rules of cricket were amended to allow players the opportunity to drink as desired when temperatures exceed 26.5°C the adverse effects of dehydration could be minimised.

Research conducted by Devlin and co-workers (2001) identified that moderate levels of hypohydration significantly impair motor skill performance required to bowl accurately without changes in anaerobic performance (i.e. maximal bowling velocity) in skilled cricket players. The authors start by highlighting that exercise-induced hypohydration has an adverse effect on physiological homeostasis and the performance of prolonged continuous, moderate intensity exercise. Although unfortunately for team sports players the impact of hypohydration on intermittent high intensity exercise has not been as extensively researched (Devlin et al. 2001). Even less is known about the effects of hypohydration on the performance of skilled motor tasks that constitute the principle components of all team sports.

The authors identify that cricket possesses the potential for high levels of hypohydration to occur as it is frequently played in a thermally stressful environment. Cricket is characterised by repetitive high intensity efforts (fast bowling), with a high degree of skilled motor performance. Therefore the aim of this study was to determine the effect of moderate levels of exercise-induced hypohydration on cricket bowling accuracy and velocity in medium-fast bowlers.

Seven male sub-elite cricket players were recruited to take part in this study. Subjects completed two experimental trials separated by ~7 days in a random order. In an effort to ensure similar pre-trial hydration status subjects ingested $8\text{ml}\cdot\text{kg}^{-1}$ of a pre-prepared sports drink, two hours prior to testing. As well as ensuring each subject was hydrated prior to testing subjects consumed a standard breakfast ($50\text{kcal}\cdot\text{kg}^{-1}$ of body weight). By standardising this protocol the authors can be relatively confident that each subject started the experimental protocol sufficiently hydrated and satiated. Each subject's body mass was recorded after breakfast and after voiding. Furthermore, a blood sample was collected after 15 minutes of seated

rest to clarify that the effort to ensure similar pre-exercise hydration status was met. One hour after breakfast subjects completed a standardised warm up (5 stages of the multi-stage fitness test) followed by individualised stretching. Subjects then bowled 6 overs under match conditions in a thermoneutral environment ($16 \pm 2^{\circ}\text{C}$, $60 \pm 9\%$ relative humidity). Subjects then performed a maximal multi-stage shuttle run test in the same thermoneutral conditions. Upon completion of the shuttle run test subjects performed ~ 1 hour of intermittent exercise in a heated room ($28 \pm 2^{\circ}\text{C}$, $\sim 40\%$ relative humidity) during which subjects attempted to consume either 80% of sweat loss (EUH) or a restricted fluid intake (HYPO). The fluid replacement trial subjects received a 600ml bolus of flavoured, coloured water immediately before and then requested to consume a further 250ml of the same solution during short (4 minutes) frequent (every 5-8 minutes) rest periods. Under the fluid restriction conditions using the same time periods as detailed above subjects consumed coloured ice blocks (30ml of the same fluid). Although data is provided concerning fluid intake there is no mention of the exact intermittent exercise protocol. After completion of the intermittent exercise subjects bowled a further 6 overs and undertook a second maximal multi-stage shuttle run in the thermoneutral environment. The magnitude of hypohydration was determined from subjects initial body mass and final body mass after correcting for fluid intake and urine loss.

During both bowling spells (6 overs) subjects were required to bowl at a target on an outdoor cricket wicket. The dependant variables were the “line” and “length” of the delivery, which was recorded by high-speed video cameras. Scores were given for each delivery, with a score of zero assigned for hitting the target. The lower the score the more accurate the bowling. The linear velocity ($\text{km}\cdot\text{hr}^{-1}$) of the cricket ball during each delivery was calculated using digitalising software.

A within subject repeated measures analysis of variance (ANOVA) was used to determine the day to day variability in the first bowling score between the two fluid replacement trials for line and length. A multivariate repeated measures ANOVA determined if a difference existed between the two-hydration trials when line and length were combined. Similar statistical procedures were used to compare bowling score, pre and post exercise induced hypohydration in both experimental conditions. The results from this study show that according to body mass subjects commenced each trial in a similar state of euhydration (89.5 ± 13.7 vs. 88.9 ± 13.4 kg) thus identifying that efforts to ensure similar pre exercise hydration were successful. As intended, subjects consumed significantly more fluid during the EUH trial than the HYPO trial (2240 ± 270 vs. 180 ± 12 ml, $P < 0.0010$). This was further supported by a significant finding of a loss in body mass from the HYPO trial (2.78 ± 0.49 vs. $0.47 \pm 0.41\%$ of body mass, $P < 0.001$). When subjects undertook the fluid restriction trial, bowling accuracy for line (16.4%) and length (15.4%) was significantly impaired (EUH 2.9 ± 0.5 , HYPO 3.4 ± 0.6 ; $P < 0.01$).

In conclusion the major finding from this study was that when subjects consumed fluid (>2 litres) during and after ~ 1 hour of high-intensity, intermediate exercise in the heat, moderate levels of hypohydration (2.8% of body mass) significantly impaired the bowling accuracy of sub-elite cricket players independent of any changes in bowling velocity.

A recent report produced by Burke and Austin (2006) on behalf of the Australian Institute of Sport (AIS) aimed to provide fluid facts for cricket. Prior to providing fluid guidelines the authors identify how much players sweat and how hydration and refuelling affects cricket. Eleven elite cricketers from the Australian squad were

recruited as subjects. Testing was conducted during a 2.5 hour training session consisting of a warm-up and drills, followed by bowling and batting practice in the nets. The weather during this morning training session was hot (~29°C, 50% relative humidity). Players had access to drink stations providing both chilled water and a commercially available sports drink. Urine samples were collected upon awakening and subsequently analysed for specific gravity. This analysis showed that 5 of the 11 players were dehydrated from the previous days activities.

The results from this report found that cricketers generally looked after themselves well, by making use of the available fluids to a rate that replaced ~72% of sweat loss (Burke & Austin, 2006). On average, players sweated at a rate of 1200ml/hr, at the individual level the results showed a four-fold difference in sweat rates between players. Fluid intake also varied, with four of the players incurring a weight loss of more than 1.5% of body mass over the session.

In identifying how hydration and refuelling affects cricket, Burke and Austin (2006) identify research (Devlin *et al.* 2001) that found that a fluid deficit (~3% of body mass) was associated with a reduction in the line and length of bowling accuracy by ~15% although speed was not effected.

Burke and Austin (2006) identify four key methods (monitoring hydration status, competition and training drinking strategies for players and issues for team management/coaches) in the provision of fluid guidelines for cricket players. The monitoring of hydration status requires tracking body weight changes over a selection of training and match scenarios. This tracking of weight changes will provide a quick check of how well fluid practices track sweat losses in a variety of exercise scenarios (Burke & Austin, 2006). The monitoring of hydration status will be reviewed in greater depth subsequently (Chapter 2.3, p 24).

The general advice for competition and training drinking strategies for players is to be aware that sweat rates and fluid needs vary according to the role in the team (e.g. bowler), playing style and environmental conditions. Therefore a fluid intake plan should be based on individual needs rather than a one size fits all approach (Burke & Austin, 2006). Warm-up, drink and meal breaks provide a good opportunity to drink fluid during a match although unfortunately these breaks fail to provide an adequate opportunity for the maintenance of hydration. When sweat losses are high players are advised to take advantage of the opportunity to drink from the boundary edge, during over changes and at the fall of wickets. During fluid replacement it is important not to drink at a rate that exceeds sweat loss, as over consumption can lead to gastrointestinal discomfort (Burke & Austin, 2006). The consumption of sports drinks is an important consideration for cricketers as these provide opportunities to intake fuel as well as fluid during matches and training. In comparison to water, sports drinks may help cricketers to perform longer and at a higher intensity for the duration of the match and maintain skills and decision-making capacity at optimal levels (Burke & Austin, 2006). Training sessions often provide the most practical opportunity to undertake monitoring of typical sweat losses in different cricket activities (Burke & Austin, 2006). Monitoring changes in body weight over the session adjusted for food and drink intake can provide a picture of sweat loss, success in replacing fluid during the session and the remaining fluid deficit at the end of the session. This information will help in the development of a fluid intake plan for training and matches, and to monitor the results from time to time.

Professional approaches for team management and coaching is to have a team drinking plan incorporating the range in needs of all players rather than relying on

good luck practices of individual players or one size fits all for the team (Burke & Austin, 2006). It is important to encourage individual or team fluid monitoring through changes in body weight and fluid intake over training and competition as it provides players with some feedback upon how well the present practices meet individual needs (Burke & Austin, 2006). The authors suggest that best practice is to provide team supplies of sports drinks and water in insulated drink coolers. Thus ensuring players have access to suitable and palatable drinks but also providing the message that hydration practices are important. It is crucial for coaches to schedule regular drinks breaks in training as to accommodate the fluid needs of the players. This should be adjusted in accordance to the intensity of the session and the environmental conditions (Burke & Austin, 2006).

A report conducted by Brearly and Montgomery (2002) on behalf of the Australian Cricket Board (ACB) investigated responses to cricket in hot conditions (~29°C). Thirty-three young cricketers (16 batsmen, 12 bowlers and 5 wicket keepers) competing in the State Institute Challenge participated in this study. Unfortunately the authors only provide a brief method detailing the experimental procedures thus reducing the repeatability of this study. Hydration status was estimated by analysis of pre-innings urine specific gravity and colour. Fluid consumption was estimated by the differences between pre and post consumption of a water bottle. Sweat rates were estimated by measuring body mass before and after innings and correcting for fluid consumption and urine output. Therefore dehydration was the difference between pre and post-mass expressed as a percentage of pre-mass. Body core temperature, blood lactate and heart rate data was also recorded from the bowlers at the end of each over. After the 5th and 10th over athletes also provided a rating of

perceived exertion (RPE) and thermal sensation/discomfort. Performance data was also recorded and analysed for the length of the subjects innings and was input by an experienced level 3 accredited coach.

The results from this study show that bowlers could improve pre-innings hydration to a urine specific gravity score of less than 1.010. This is important, as pre-innings hydration soon becomes poor hydration while playing in hot conditions due to the high sweat rates (Brearley & Montgomery, 2002). The authors suggest that if urine specific gravity cannot be measured urine colour provides an adequate measure of hydration in the field that allows for immediate feedback. This study also identified that bowlers had the highest sweat rates (1.1 litres/hr), bowling a spell of 10 overs with the inclusion of non-bowling periods, sweat rates reduced to ~0.75 litres/hr. Since the fluid consumption was lower than sweat rate, dehydration was related to time. Therefore the bowlers attained the highest average dehydration equating to ~1.5% decrease in body mass. The analysis of bowling responses showed that heart rates were maintained at a moderate to high intensity effort for the duration of the bowling spell. For the total duration of the innings bowlers spent the majority of the time at or above a maximal heart rate of 75%, although unfortunately the authors fail to provide data on the actual times. Higher intensities of maximal heart rate of 82 and 87% equated to ~24 and 12% of total time respectively. From this it is clear that fast bowlers must be well conditioned to cope with these extended demands of high intensity exercise (Brearley & Montgomery, 2002). Thus supporting the earlier findings (Noakes & Durandt 2000) highlighting the high levels of fitness in elite cricketers.

In conclusion hot conditions (~29°C) can impose moderate levels of thermal stress during one-day cricket and pre-innings hydration and dehydration must be assessed to limit this stress.

Chapter 2.2 – Team Sport Literature

Research conducted by Burke (1997) investigated fluid balance during team sports. The author identifies that team sports are played throughout the world and despite the immense popularity and the large numbers that participate there still have been few systematic studies of the nutritional needs of team sport players. The purpose of this study was to review fluid balance in team sports, identify issues related to fluid intake and sweat loss.

Sweating is the body's most important means of dissipating the excess heat generated as a by-product of muscular work or gained from a warm environment (Burke, 1997). Sweat losses in team sports differ in a number of ways from sweat losses during continuous effort events (running and cycling) and as a result are not well documented. Firstly the workload in team sports generally involves periods of high-intensity exercise interspersed with recovery periods of low-intensity activity and formal rest breaks (Burke, 1997). Secondly every competition is unique and therefore even in a standardised environment a player may experience large differences in sweat loss from game to game. The final issue for consideration is that many team sports are played in conditions or with rules and customs that are inappropriate for temperature regulation and optimal sweating function (Burke, 1997). Cricket is of no exception and has attracted criticism of the size, weight and fabric of the team uniform as well as the protective gear.

The opportunity to ingest fluid during team sports is governed by different factors, although mainly by the style of play and the rules of the game. The regulations of cricket limit fluid intake to recognised drinks breaks every 40-60 minutes. It is clear that such rules prevent adequate fluid replacement, particularly in hot conditions where sweat rates are high (Burke, 1997).

In conclusion, Burke (1997) identifies that there is a potential for sufficient hypohydration to occur, especially when games or training sessions are undertaken in hot environments. In hot conditions it is suggested (Burke, 1997) that a goal of maintaining fluid deficits to below 2% of body weight may be more practical. Unlike sports with a continuous-moderate intensity, specific guidelines for team sports are impractical since there is no consideration for the vast inter and intra-individual differences in fluid needs in players involved in the same sport (Burke, 1997). The final part of this paper provides general guidelines for individuals in team sports and will be discussed subsequently, as this was further developed with the inclusion of another author.

Research conducted by Burke and Hawley (1997) investigated fluid balance in team sports concluding with the provision of guidelines for optimal practices. The authors present detailed findings from studies that have determined body water losses and fluid intake practices from a variety of sports. Although for the purpose of this review only findings specific to fast bowlers will be detailed, concluding with guidelines for sound hydration strategies during training and competition.

The first topic reviewed in this paper was fluid loss during team sport. Unfortunately for team sport players there are a number of ways in which sweat losses incurred differ from that of prolonged continuous exercise. This is due to the

work rate being largely intermittent, unpredictable and random in nature (Burke & Hawley, 1997). The exercise requirements vary markedly according to the level of competition, field positions and style of play for each participant. Moreover every competition is literally a “new ball game” and as such, even in standardised environmental conditions a player may experience large differences in sweat loss from game to game. As a result, team players are less able to anticipate sweat losses (Burke & Hawley, 1997).

The second topic reviewed identifies fluid intake during team sports. The main disadvantage for team sport players is that the majority of the current beliefs about voluntary fluid intake is based upon observations from continuous moderate intensity exercise (Burke & Hawley, 1997). Fluid intake is influenced by a complex interaction of physiological and behavioural controls. The thirst drive is controlled by factors such as plasma osmolality and is inadequate in promoting rapid replacement of sweat losses (Burke & Hawley, 1997). The main fundamental reason why fluid intake differs from that of prolonged sub-maximal exercise is due to rules surrounding the game, only permitting fluid intake at certain times (every 40-60 minutes during cricket).

The third topic reviewed investigated the effect of hypohydration on thermoregulation and performance during team sports. Like fluid loss, the impact of hypohydration on intermittent high intensity exercise has not received a great deal of scientific research. Team sports are characterised not only by intermittent high intensity exercise, but also by the contribution of skill and the importance of mental functioning on motor performance. Therefore hypohydration could potentially have a greater impact on the performance of individuals participating in team sports

which require this overlay of cognitive function in comparison with sports such as cycling that requires gross locomotor activities (Burke & Hawley, 1997).

The fourth topic to be reviewed examines the requirements for the consumption of carbohydrate and electrolyte beverages during team sports. The primary aims of fluid replacement during team sports are to provide a source of energy (carbohydrate) for the exercising muscles and to prevent the negative effects of exercise induced hypohydration. Very few studies have investigated the effects of carbohydrate feedings on performance during intermittent, high intensity exercise the typical activity pattern associated with most team sports and fast bowlers in particular. Part of the reason for this scarcity of data is due to the practical difficulties associated with field studies in assessing the efficacy of specific nutritional practices (Burke & Hawley, 1997). Another important consideration is that the outcome of the match is likely to be influenced by the opposition players, tactical considerations, skill level, motivational factors and the prevailing climatic conditions. Thus further highlighting the difficulty in investigating the effect of fluid supplementation consumed during team sports. Finally, Burke and Hawley (1997) identify that it is extremely difficult to determine the effects of ingesting various fluid supplements on measures of motor skill proficiency, concentration and technique all required to perform in a team sport. Although it should be noted that there are no studies in the literature showing that after the ingestion of a carbohydrate solution, exercise performance or motor skills are impaired when compared to the ingestion of water alone. Furthermore commercial carbohydrate-electrolyte solutions are more palatable than plain water thus increasing a player's voluntary fluid intake. As a result of this carbohydrate-electrolyte solutions should be chosen in preference to water (Burke & Hawley, 1997).

The final section to this study provides recommendations for hydration practices for team sport players. Identifying that compared to most endurance events many team sports offer frequent opportunities to ingest adequate volumes of fluid and thus prevent exercise-induced hypohydration. Therefore, Burke and Hawley (1997) provide strategies aimed at improving the awareness and knowledge of team sport players and coaches. An important consideration is that these strategies are general and should be adapted to each player and each unique sporting situation.

Chapter 2.3 – Hydration Testing Literature

Research conducted by Oppliger and co-workers (2005) investigated the accuracy of urine specific gravity and osmolality as indicators of hydration status. Proper hydration plays a significant role in the performance of athletes and at the extreme acute dehydration is a significant health risk that can result in heat stroke and death (Oppliger, Magnes, Popowski & Gisolfi, 2005). Decrements in physical performance primarily associated with cardiovascular function and thermoregulation have been documented by the American College of Sports Medicine (ACSM, 1996) and more recently by the National Association of Athletic Trainers (NATA, 2000).

In response to the potential health and safety risks associated with dehydration the ACSM have recommended conducting greater care when measuring hydration status. There are simple methods used to measure hydration status, which include diurnal weight change and the monitoring of urinary markers including colour, specific gravity and osmolality. Although for the purpose of this study a greater emphasis will be placed upon urine colour and osmolality. As well as the

recommendations in place for monitoring hydration status there are threshold values that represent dehydration from minimal to severe (Oppliger et al. 2005). The NATA associates minimal dehydration (1-3% decrease in body weight) with “straw” coloured urine. Although the research supporting these recommended thresholds are limited. Armstrong and colleagues (1994; 1997 & 1998) is one of the main groups of lead researchers who focus on markers for hydration status both in a laboratory setting and in the field. This research found a strong correlation ($r = 0.97$) between urine specific gravity (USG) and urine osmolality.

The aim of this study was to evaluate the use of USG and urine osmolality as markers of dehydration, with particular interest on the recommended cut offs suggested by Armstrong et al. (1994) and Shirreffs and Maughan (1998) respectively. This study was separated into two parts, the first evaluating the response to urine osmolality to change in hydration status ranging from euhydrated to 5% of weight loss by dehydration and the second evaluating the accuracy of urine osmolality in the field against a criterion measure of plasma osmolality.

Part 1: Twelve physically fit male athletes were recruited to take part in this study. Subjects were recruited as long as they could endure exercise in the heat for a sufficient duration to achieve a weight loss equal to 5% of total body mass. To ensure adequate hydration subjects were instructed to consume water frequently on the day preceding the study. Unfortunately as subjects were instructed to drink frequently one individual’s perception of frequent drinking could largely differ from another’s. If specific amounts of water were instructed to be drunk this would strengthen the method especially as upon awakening prior to attending the amount of water subjects were required to drink was quantified (250ml). Upon arrival subjects hydration status was assessed by USG, if these values exceeded the cut off

(>1.015) subjects were excluded from testing. Subject who were still permitted to participate subsequently voided and newd body mass recorded. The urine samples and a 10ml blood sample (taken from a forearm vein) were used in the determination of USG, urine osmolality and plasma osmolality.

Subjects entered an environmental chamber (43°C, 20% relative humidity) and exercised on either a treadmill or cycle ergometer to elicit dehydration of 1,3 and 5% of total body mass. After losing 5% of body mass subjects undertook a 60-minute recovery period consuming chilled (~10°C) distilled water equivalent to the amount of weight lost. At each stage of dehydration (1,3 and 5% of body mass) and 30 and 60 minutes into recovery blood and urine samples were collected.

Part 2: In this study blood and urine samples were collected from 51 subjects consisting of 16 1st division, 31 2nd division wrestlers and 4 physically active non-wrestlers, although there is no definition determining physically active (i.e training 4h/week). Measurements were taken at various times of the day (10 AM, 2-3 PM and 4-5 PM) in which subjects activities varied widely from, being sat in a lecture to competing in wrestling practice. Both urine and plasma samples were collected and stored on ice until subsequent osmolality analysis, although there is no mention of this time duration.

Data was analysed using a repeated measures ANOVA to identify differences between baseline, 1, 2, 3 and 5% dehydration and 30 and 60 minutes of rehydration. Pearsons correlations were conducted to compare the association between USG and urine osmolality.

The main findings from this study are that incremental changes in plasma osmolality were shown as subjects dehydrated by 5% of body weight and subsequently rehydrated, while urine osmolality showed delayed changes. Using the

medical decision model, sensitivity and specificity were not significant ($P > 0.05$) at selected cut offs for urine osmolality. At the most accurate, cut off values for urine osmolality 700 and 800 mosm/kg were correctly analysed only 63% of the time.

In conclusion, Oppliger et al. (2005) identifies that plasma osmolality is the best method in determining hydration status and appears sensitive to small changes in hydration status. The authors do however identify that in the field setting this method lacks feasibility because of equipment needs, cost, technical assistance etc. Therefore under field conditions the authors suggest including a history of activity and fluid consumption questionnaire as these factors might indicate factors influencing hydration status.

Research conducted by Shirreffs and Maughan (1998) investigated urine osmolality and conductivity as indices of hydration status in athletes in the heat. Significant sweat loss is associated especially when performing prolonged exercise in high ambient temperatures and humidity.

Thirst is rather an insensitive mechanism in man and the levels of dehydration that is likely to impair athletic performance are commonly incurred before the need to drink is perceived. Therefore having a reliable simple index of hydration status would be of great use to coaches and athletes. The authors provide a clear statement outlining the three aims of this study. The aims of this study were to report results of measurements of urine osmolality made on individuals either euhydrated or moderately hypohydrated. Discuss the findings from three groups of athletes during a period of warm weather training and finally assesses the use of a portable conductivity meter as a practical field measurement of urine concentration by

athletes. For each of the three separate aims to be met three separate methods were used.

Part A: Eleven healthy sedentary individuals were recruited to take part in this study and provided urine samples on five consecutive days. Subjects were encouraged to carry on as normal, placing no restrictions on diet or activities. The first urine sample of the day was collected and retained for later analysis, a short time after rising, before breakfast. A second group of subjects ($n = 10$) lived under the same environmental conditions and undertook exercise on a cycle ergometer in a warm ($35.2 \pm 0.4^{\circ}\text{C}$) humid ($67 \pm 5\%$ humidity) environment on seven evenings, with each experimental session being separated by ~ 7 days. A total of 40 minutes of exercise was undertaken in 10-minute bouts separated by a 5-minute rest period. Although the environmental conditions and exercise protocol are well described there is no mention of the exercise intensity subjects cycled at. After exercise in the evening food (pizza or chips) was consumed prior to subjects retiring to bed, the only fluid consumed ($\sim 150\text{ml}$) was from the food. The following morning urine was collected and retained under the same protocol as identified earlier for subsequent analysis.

Part B: Twenty-nine male athletes competing at an international level from three separate sports (gymnastics, boxing and wrestling) were recruited to take part in this study. Urine samples were provided and collected under the same protocol as detailed in Part A. All urine samples were provided and collected during a short period (~ 11 days) of warm weather training with high daily temperatures ($28\text{-}34^{\circ}\text{C}$) and varying humidity ($\sim 60\text{-}90\%$).

Part C: Five subjects were recruited to take part in a study investigating post exercise hydration. Proceeding an over night fast subjects were instructed to

consume water (500ml) two hours prior to arriving at the laboratory, by standardising this the authors strengthen the method as all the participants arrive at the laboratory consuming the same amount of water. Upon arrival subjects were seated for 15 minutes, after which a urine sample was collected. A second urine sample was collected 30 minutes after completion of a series of intermittent exercise bouts sufficient to induce a state of hypohydration (a loss of $2.1 \pm 0.14\%$ of body mass) in the heat. Subject then consumed a volume of fluid equivalent to 150% of mass lost with dehydration over one hour. Fluid intake was either a commercially available sports drink or a chilli beef and rice flavoured water. A third urine sample was collected at the end of this one-hour period with additional collections at; 1, 2, 4 and 6 hours after this time. Urine collection for these subjects were under the same protocols as identified earlier in Parts A and B thus strengthening the method.

The data from Parts A and B was analysed by a one-way ANOVA, with part C values presented as median and range values.

The main findings from this study showed a significant difference ($P < 0.001$) in osmolality between subjects being moderately dehydrated compared to being euhydrated. The osmolality of the first morning urine for the control subjects averaged over five days was $675 (\pm 232)$ mosmol.kg⁻¹. For subjects who were hypohydrated by exercise and fluid restriction an averaged (7-days) first morning urine sample of $924 (\pm 99)$ mosmol.kg⁻¹ was recorded. Although a significant difference was found the urine samples compared were from two separate groups of people as opposed to the same individuals. In the field measurements from athletes undertaking warm weather training, the authors identified that with the appropriate amount of feedback satisfactory hydration levels could be maintained.

In conclusion, research by Shirreffs and Maughan (1998) highlighted that the osmolality of first morning urine is influenced by hydration status. Even with a moderate level of hypohydration ($1.85 \pm 0.38\%$ of body mass) the osmolality of the first morning urine is elevated relative to the euhydrated state. Therefore an Osmometer is suggested in being an effective tool in providing athletes reliable information about hydration status.

Research conducted by Armstrong and colleagues (1998) investigated urinary indices during dehydration, exercise and rehydration. Earlier research conducted by Armstrong and co-workers (1994) was the first study to examine urinary indices of hydration status and provides adequate background information (see Appendix I for review of this paper).

The authors start by highlighting that the thirst drive does not stimulate drinking until water loss reaches 1-2% of body mass and it is likely that athletes routinely train and compete at an unrecognised level of hypohydration. Many authorities have advised athletes to evaluate fluid balance either by observing sweat loss, fluid intake and/or body mass. However these techniques are inaccurate unless all food, beverages, sweat, respiratory water loss and excrement are carefully weighed and accurately interpreted. Although other authorities predominately in weight classification sports have recommended urinalysis as a screening tool as it is a non-invasive evaluation of a body fluid. Unfortunately this is rarely performed as laboratory analysis requires technical expertise and is costly (Armstrong et al. 1998). In an attempt to simplify direct body fluid analysis, nutritionists and exercise physiologists have advised athletes to observe urine colour as an index of hydration

status. Therefore the purpose of this study was to evaluate the validity and sensitivity of urine colour, USG and urine osmolality as indices of hydration status. Male trained cyclists ($n = 9$) who competed in road or off-road races were recruited to take part in this study. Preliminary testing confirmed the trained status of subjects as VO_{2peak} values were provided ($60.3 \pm 3.9 \text{ ml.kg}^{-1}.\text{min}^{-1}$). Each subject completed one 42-hour period in which observations were made under conditions of normal hydration, exercise induced dehydration, a strenuous exercise bout in a hot environment and a lengthy rehydration phase. During the 24 hours prior to dehydration subjects were required to consume water or non-caffeinated fluids (30ml.kg^{-1} body mass) to ensure proper hydration. This protocol takes into account individual differences in body weight and will provide standardised fluid intake regardless weight. Subjects were required to report to the laboratory on day 1 (10am – 12 noon) in a euhydrated state, at least 14 hours after the last meal was consumed. The hydration status for each subject was quantified by measuring USG, body mass and plasma osmolality. The aim of the subsequent dehydration phase was to decrease body mass by 4% this was achieved by making subjects perform 2 hours of moderate-intensity cycling exercise wearing multiple layers of clothing to enhance sweating as well as restricting fluid intake (21 ± 2 hours). After the dehydration level (4% decrease in body mass) had been verified on day 2 (7 - 11 am) subjects entered an environmental chamber ($36.7 \pm 0.2^{\circ}\text{C}$) and performed an exercise bout intensity of (70% VO_{2peak}) to volitional exhaustion (18.9 ± 2.7 min) on a cycle ergometer. The data provided above increases the repeatability and therefore strengthens this paper. Subjects were then instructed to resume normal drinking and eating habits and begin the rehydration phase of this protocol. During two return visits to the laboratory at 4 hours (± 1 hour) post exercise in the afternoon of day 2

and 21 hours (± 1 hour) post exercise in the morning of day 3 body mass and fluid samples were collected and recorded. Subsequently the authors provide a clear and concise method, detailing exact protocols for the assessment and a detailed description of all equipment used in the analysis of blood and urine samples. Thus strengthening the repeatability of this method.

The outcome variables in this study were investigated for significance against time with the use of a one-way repeated measures ANOVA, followed by post-hoc analysis (The Newan-Keuls) to determine specific differences. Pearson product moment correlation coefficients were also calculated for selected variables across all time points.

The main findings from this study were interpreted into practical applications. Therefore exercise, large gains and losses of body water and the intake of a variety of rehydration fluids do not alter the validity of urine colour, osmolality or USG as indices of hydration status (Armstrong et al. 1998). Thus concluding that athletes may utilise urine colour as an index of hydration status in tracking body water changes as it is strongly correlated ($r = 0.80$) with urine osmolality.

Research conducted by Oppliger and Bartok (2002) provides the current opinion concerning hydration testing of athletes. The authors start by identifying that every year severe dehydration results in injury and death of many athletes. Therefore it is no surprise that position statements (American College of Sports Medicine and National Athletic Trainers' Association) have been produced to warn athletes, coaches and athletic trainers about the dangers associated with dehydration. These guidelines also provide a comprehensive guide to staying well hydrated, the amount and rate of fluid consumption, palatability and nutritional composition of

rehydration fluids for both training and competition. However the authors identify that the main problem with these position stands is the paucity of information on hydration testing. With this in mind the aim of this study was to examine conditions under which hydration testing may be important, provide criteria for assessing hydration, evaluate several common methods for assessing hydration status and finally offer recommendations for evaluating the outcome of a hydration testing.

Conditions for hydration testing

There are two broad categories under which hydration testing would be of value. The first includes monitoring of athletes either by the athlete or the teams medical staff during training and or competition to ensure health and safety. The second includes the assessment of hydration status prior to certification in weight classification sports. Although for the purpose of this study the latter will be excluded, as fast bowlers do not need to meet a certain weight to compete. A vigorous training schedule is not uncommon for elite athletes and as a result of this would frequently face conditions resulting in the performance of multiple bouts of competition during a period of a few days (i.e. LV County Championship matches). While opportunities to replace fluids may be available to cricketers in these situations many fail to return to a euhydrated state on a daily basis (Oppliger & Bartok, 2002). This is because the thirst mechanism may not be enough to encourage proper restoration of body water. With this in mind it is critical for teams to have proper hydration monitoring protocols in place as well as teaching athletes self-monitoring techniques.

Methods for hydration testing

Monitoring Bodyweight Stability: For athletes in any sport, the majority of fluid lost during exercise occurs as a result of the body's thermoregulatory responses, which includes sweating. In addition to exercise, environmental conditions have a significant effect on sweating. The simplest method in measuring hydration is by monitoring daily weight changes using professional scales. When monitoring hydration through weight changes it is important to follow a standardised protocol, which generally requires the athlete prior to practice/competition to present minimally clothed and again following the exercise bout having towelled of excess sweat. In conclusion, monitoring weight using a standardised protocol (as detailed above) is a simple, non-invasive and valid method for hydration testing, providing both clinicians and athletes with an effective tool for daily hydration monitoring.

Monitoring Urinary Volume, Colour and Composition: Under conditions of progressive dehydration, urine shows acute changes in volume, colour and osmolality. Under normal conditions urine volume averages 1.5-2.5 l/day has an osmolality of <500mosm/l and is characterised by having a pale to light yellow (straw) colour (Oppliger & Bartok, 2002). The measurement of urinary markers of dehydration is inexpensive although it does require an element of expertise from the technicians, although these skills can be easily mastered.

The measurement of urinary volume uses a quantitative method and requires compliance by the athlete and co-operation in the collection process. The technique to analyse urine osmolality traditionally requires a trained technician and a freezing point osmometer. The osmometer measures the amount of osmoles of solute particles per kilogram of solution. When analysing urinary colour Armstrong et al.

(1994) validated a six point likert scale for monitoring urine colour. A pocket size copy of the colour scale can provide clinicians and/or athletes with a simple and inexpensive method of assessing dehydration. With the exception of an osmometer, the methods of urine testing detailed above provide immediate feedback to athletes and medical staff upon hydration status. Therefore urine osmolality, colour and volume provide easy to use indices for testing hydration status among athletes, especially as the assessment of colour and volume can be easily demonstrated.

In conclusion, the authors recommend that teams have a written protocol in place that discusses the value of hydration testing related to health and safety, as well as providing specific protocols for the assessment of hydration status. It is important to note that hydration testing especially in the field is not perfect. Although the advantages of hydration testing as a tool to enhance athletic performance and decrease health risks are clear to see (Oppliger & Bartok, 2002).

Research conducted by Horswill (1998) extensively reviews the literature surrounding effective fluid replacement. Horswill identifies a clear structure to this paper by identifying the three main areas to be addressed in this paper; how fluid is lost, the importance of replacing fluids and the most effective way of fluid replacement.

Routes of fluid loss

The route of daily fluid loss in a sedentary human can exceed 3 litres and with the inclusion of physical training this water loss can easily double (Horswill, 1998). This is because sweating is the major mechanism for heat dissipation. During

physical performance the rate of fluid loss for athletes can exceed 2 l/hr although this rate will vary tremendously due to a number of factors. These factors include skin surface area, work intensity and environmental factors. The rationale for having individual fluid loss data as opposed to a general overall team data is of a much greater benefit as there are a multitude of factors (as identified earlier) that influence an athletes sweat rate (Burke & Austin, 2006).

Effects of fluid loss

The effects of dehydration on performance may vary depending upon the type of performance and the degree of dehydration, a clear effort has been made to provide distinctions for each of the three general types of effort based on the energy systems. For the purpose of this investigation the focus will be on high intensity effort sustained or repeated intermittently, the effort typically experienced by fast bowlers. This includes anaerobic efforts, long enough in duration to rely more on anaerobic glycolysis than phosphagen fuels (Horswill, 1998). This review (Horswill, 1998) identifies that the literature is equivocal although there does appear to be a trend for a decrement in this type of performance when subjects are dehydrated (Horswill, 1998). As high power efforts are repeated or sustained, blood flow and aerobic metabolism begin the more important components of the recovery, particularly during the rest period between intervals of work. Since blood flow is reduced and heat production accumulates, performance of such efforts will eventually become negatively effected (Horswill, 1998).

Drivers of fluid replacement

Considerable research has been conducted to demonstrate the characteristics of a fluid that may impact the volume consumed. Horswill (1998) identifies the four main factors that may impact the volume of fluid consumed as; palatability, absorption, electrolyte content and ergogenic benefits.

It is well established that having access to flavoured, sodium containing fluid will increase the volume consumed and thus the reducing the chance of dehydration (Horswill, 1998). Temperature also influences palatability. This had been identified in the position statements from both the ACSM (1996) and more recently by the NATA (2000), suggesting acceptable temperatures of fluid ranging from 15-20°C and 10-15°C respectively, although these values should be viewed as guidelines not absolutes.

The presence of electrolytes in a fluid can have an impact on voluntary fluid intake. The critical electrolyte is sodium, as it plays an important role in the thirst mechanism. In addition to stimulating thirst by elevating plasma osmolality, sodium also helps in maintaining fluid balance in both plasma volume and total body fluid balance (Horswill, 1998). The latter is important in the recovery process so that the athlete starts the subsequent training session or competition in a euhydrated state. Another function of sodium and possibly other electrolytes is in restoring of sodium and electrolytes lost in sweat as well as stimulating the fluid and carbohydrate uptake in the gut.

While having an ergogenic benefit does not directly stimulate drinking, the knowledge that a beverage can enhance performance may entice athletes to a particular fluid and thereby indirectly promote hydration. The key ingredient in this

sense is energy or carbohydrate. Regardless of the exact mechanisms the information available concerning muscle glycogen maintenance and performance enhancement supports the recommendation for athletes in team sports to consume carbohydrate during competition (Horswill, 1998).

In conclusion, due to the high rate of fluid loss in athletes and the tendency not to meet fluid needs voluntarily, it is critical that behavioural strategies are in place to ensure adequate hydration during training. Therefore the strategies that incorporate the guidelines suggested by the ACSM (1996) and the NATA (2000) on fluid needs are encouraged.

Research conducted by the National Athletic Trainers Association (2000) provides a position statement for fluid replacement for athletes. The purpose of this position stand is to provide recommendations for athletes to optimise fluid replacement, emphasise the physiologic, medical and performance considerations associated with dehydration and finally identify the factors that influence optimal rehydration during and after athletic participation.

Recommendations

The NATA provide a considerable amount of recommendations with the majority being general therefore for the purpose of this review only recommendations that can be applied for cricketers will be mentioned.

It is important to establish a hydration protocol for athletes including a rehydration strategy considering sweat rates, environmental factors, exercise duration and intensity. A proper hydration protocol considers each sports unique features. If

rehydration must occur during a specific time the athletes must consume fluid to maximise hydration within the sports confines and rules. Athletes should begin all exercise sessions well hydrated, therefore the consumption of ~500ml of water or sports drink 2-3 hours before exercise is recommended. Fluid replacement should approximate sweat and urine losses and at least maintain hydration at less than a 2% reduction of body weight. The inclusion of sodium chloride in fluid replacement beverages should be considered especially when physical activity is conducted in hot weather. Under these conditions adding modest amounts of salt (0.3-0.7g/l) can offset salt lost in sweat and minimise medical events associated with an electrolyte imbalance.

After these recommendations the NATA provide a comprehensive review on all areas of fluid replacement for athletes although for the purpose of this paper only factors concerning rehydration, hydration before exercise, rehydration during exercise and the composition of a rehydration fluid will be covered.

One main factor influencing rehydration is the degree of environmental stress. The environmental stress is determined by; temperature, humidity and wind speed which all induce physiologic changes that effect the rehydration process (NATA, 2000). Once ambient temperatures rise above 28°C fluid intake increases substantially this is seen further when fluid consumed is chilled.

It is considered crucial for an athlete to begin exercise well hydrated. Many athletes who perform repeated bouts of exercise on the same day become chronically dehydrated (NATA, 2000).

When the focus shifts to rehydration during exercise the primary aims are to decrease the rate of hyperthermia and more importantly for this study the maintenance of athletic performance. Athletes do not generally hydrate to pre-

exercise levels during exercise due to personal choice, fluid availability, the circumstances of competition or a combination of these factors. The aim is for athletes to drink quantities equal to sweat and urine losses and while athletes rarely meet this goal the large volumes (>1 l/h) can be readily consumed to maintain hydration (NATA, 2000). It is important to appeal to individual taste preferences to encourage athletes to drink more fluid. Including CHO and electrolytes in the rehydration drink can maintain blood glucose, CHO oxidation and electrolyte balance and therefore maintain performance if the exercise session exceeds ~50 minutes in duration (NATA, 2000). Therefore this is of importance to fast bowlers especially as bowling spells can regularly exceed 50 minutes. During exercise the body uses 30-60g of CHO per hour, thus replacing these amounts will assist in maintaining CHO oxidation and delay the onset of glycogen depletion. Therefore including 60g of CHO in 1 litre of fluid will not hinder fluid absorption and provides an adequate supply of CHO during or while recovering from an exercise bout.

Research conducted by the American College of Sports Medicine (1996) provides a position stand on exercise and fluid replacement. This position statement is based on a comprehensive review and interpretation of scientific literature concerning the influence of fluid replacement for exercise performance. Based on the available evidence the ACSM provide seven general recommendations on the amount and composition of fluid that should be ingested in preparation for, during and after exercise.

Fluid replacement following exercise represents hydration prior to the next exercise bout. Therefore any fluid deficit prior to exercise can potentially compromise

thermoregulation during the next exercise session, if adequate fluid replacement is not employed. Exercise performance over both a short duration and which requires a high power output typically experienced by a fast bowler can be impaired when individuals begin exercise with the burden of a previously incurred fluid deficit (ACSM, 1996). This deficit becomes magnified when performing in a hot environment. Following a fluid deficit created by exercise, individuals ingest more fluid and retain a higher percentage of this ingested fluid when electrolyte deficits are also replaced. In fact complete restoration of a fluid volume deficit cannot occur without electrolyte replacement in food or beverages (ACSM, 1996).

During exercise, humans do not typically drink as much water as they sweat and at best voluntary drinking only replaces about two thirds of body water lost as sweat. It is common for individuals to dehydrate by 2-6% of body mass during exercise in the heat, despite the availability of adequate amounts of fluid (ACSM, 1996). While large volumes of ingested fluids (1 L/h) are tolerated by exercising individuals in laboratory studies, field observations indicate that most participants drink sparingly during competition. This is supported by Gore et al. (1993) who observed drinking rates of ~0.55 L/h.

Enhancing palatability of an ingested fluid is one way of improving the match between fluid intake and sweat output. In general, fluid replacement beverages that are sweetened, flavoured and cooled to between 15-21°C should stimulate fluid intake (ACSM, 1996).

The rate at which fluid leaves the stomach and is absorbed from the intestine and into the blood is dependant on a complex interaction of several factors, such as volume, temperature, composition of the ingested fluid and the exercise intensity, with the most important factor influencing gastric emptying is the fluid volume in

the stomach (ACSM, 1996). Although the rate of gastric emptying of a fluid is slowed proportionally with increasing glucose concentration above 8% (ACSM, 1996). There is little physiological basis for the presence of sodium in an oral rehydration solution for enhancing intestinal water absorption as long as sodium is sufficiently available from the gut from the previous meal. The primary rationale for electrolyte supplementation in a fluid replacement beverage is to replace the electrolytes lost through sweating during exercise greater than 4-5 hours in duration (ACSM, 1996). The addition of CHO to a fluid replacement solution can enhance intestinal absorption of water. However the primary role of ingesting CHO in a fluid replacement beverage is to maintain blood glucose concentrations and enhance carbohydrate oxidation. To maintain blood glucose levels during moderate-to-high intensity exercise carbohydrates should be ingested throughout exercise at a rate of 30-60 g/hr.

In conclusion, the primary objective for replacing body fluid loss during exercise is to maintain normal hydration. It is important to consume adequate fluids during the 24 hour period before, and even consume ~500 ml of fluid 2 hours before exercise. During exercise lasting longer than one-hour carbohydrates and electrolytes should be added to the fluid replacement solution to maintain blood glucose, delay the onset of fatigue and enhance palatability, respectively.

The aim of this study was to describe the physiological demands faced by fast bowlers during a single competitive match and training session.

Chapter 3 – Method

Subjects

Prior to testing, approval for the experimental procedures was obtained from the School Research Ethics Committee of the University of Chester (Appendix II). Subjects ($n = 2$) were recruited dependant on the level of participation (sub-elite) and were contacted by letter (Appendix III) detailing the proposal of this study. After being informed verbally and in writing of the full experimental protocols, risks and benefits associated with participation (Appendix IV) subjects provided written informed consent (Appendix V) in accordance with the policy of the University of Chester. Subjects completed a medical history questionnaire (Appendix VI) indicating that neither subject had previously experienced any issues preventing them from participating in this study. The bowlers (second team) who took part in this study consisted of one opening bowler and one first change bowler. Subject characteristics (age, height and mass) are summarised below (Table 1). For the purpose of this study a fast bowler was defined in accordance with the England and Wales Cricket Board (ECB) as; a bowler to whom a wicket keeper in the same age group would in normal circumstances stand back to take the ball (ECB, 2007).

Table 1. Subject characteristics.

Subject Number	Age (yrs)	Height (cm)	Mass (kg)
1	21	177	76
2	20	179	75

Preliminary testing

Prior to the experimental conditions being conducted subjects were familiarised with all testing procedures on two separate occasions. Each habituation session was separated by a minimum of three days (13/08/2007 & 19/08/2007). During these habituation sessions subjects were familiarised with the sensations of wearing a Polar heart rate monitor (Polar Electro Oy, Kempele, Finland) and two sweat patches (Opsite Plus, Smith and Nephew, England). A further advantage of this habituation was to identify the potential of any allergic reaction experienced by the wearing of the sweat patches.

The match

All measurements were taken from players on the same team, for the duration of bowling in the first innings of a home match in the Second XI Championship (England). The majority of teams competing in this competition are reserve grade teams for the elite LV County Championship teams; therefore, this standard of play may be classified as sub-elite.

The match lasted three days and all data was completed in August 2007 during the second half of the season in a clear and dry playing environment. The thermal environment was assessed using hourly measurements of a wet and dry bulb thermometer (Brannan, England). From these measurements the wet bulb globe temperature index (WBGT) was calculated (McCann & Adams, 1997). Both bowlers were measured under actual match conditions in weather that approximated a warm day (forecast ambient temperature 19°C) during the 2007 season. The game

was played under the ECB playing regulations governing second eleven cricket (Appendix VII) consisting of two innings for both teams with no bowling restrictions upon overs bowled by an individual player.

Each day of play used the time intervals of County Championship matches (ECB, 2007), that is;

1 st , 2 nd & 3 rd day	Start -	11:00
	Lunch -	13:15- 13:55
	Tea -	16:10 – 16:30
	Close -	18:30

The team, in which the players were investigated during the match, won the match by 105 runs. Fluids were available to subjects during the actual match conditions, that is ad libitum pre match as well as during the lunch and tea breaks. Drinks were provided every hour during all three sessions. Individual players were also allowed to receive a drink either on the boundary edge or at the fall of a wicket in accordance with the laws set by the International Cricket Council (ICC, 2006).

The training session

All data was collected during a single routine 150-minute training session in September 2007. The thermal environment was assessed using hourly measurements of a wet and dry bulb thermometer (Brannan, England). Both bowlers were measured under a training environment in weather that approximated a warm day (forecast ambient temperature 17°C) during the 2007 season. This was the first

training session of the day for these players and was carried out between 09:30 hrs and 12:00 hrs.

Training consisted of a warm-up, 6-a-side games, fielding drills, bowling in the nets followed by a warm-down. The bowlers bowled as per normal training conditions alternately delivering the ball, while the batsman batted as per match conditions. During training, fluid was also available to subjects under the same conditions as competition, which is ad libitum. Two practice nets at a first class County Ground were used for the training session, with two bowlers and one batsman assigned to each net. The total duration of the training session was approximately 150 minutes, and both bowlers followed the same training program.

Experimental design

In determining the test protocol for this study it was considered important to ensure that the data was capable of comparison to existing findings and reflect as closely as possible the physiological and hydrational demands experienced by fast bowlers in competition and training. The standard protocol was designed to minimise disruptions to subject's normal routines. Therefore all fluid was consumed ad libitum thus highlighting the potential need to educate subjects about the importance of fluid consumption, as voluntary consumption had been identified (Gore et al. 1993) as being inadequate.

All testing procedures took place on the ground of a first class county ground consisting of an oval playing ground with a professionally prepared wicket as well as training nets. All players were required to wear full cricket whites during every stage of data collection, which consisted of a short sleeve cotton shirt, polyester

trousers, underpants, cotton or wool socks and cricket shoes of their own choice. Batsmen wore full protective equipment, which includes leg pads, gloves and a helmet.

Measurements were taken over a period of one cricket match and training session and provided information upon warm (2-3°C above national average) temperatures (Met Office, 2007).

The primary aim of fluid replacement for team sports is to provide a source of energy (carbohydrate) for the exercising muscles and to prevent the negative effects of exercise induced dehydration (Burke & Hawley, 1997). Disturbances in body water and electrolyte balance can adversely affect cellular and systematic function, thus subsequently reducing the ability of humans to tolerate prolonged exercise (Armstrong, 2000).

The addition of carbohydrate (~7% concentration) in a fluid replacement solution is recommended for exercise lasting longer than one hour, since it does not significantly impair water delivery to the body and may enhance performance (Armstrong, 2000). The inclusion of electrolytes predominantly sodium (0.5-0.7g.L⁻¹ of water) in a fluid replacement solution ingested during exercise lasting longer than one hour is recommended as it can be advantageous in enhancing palatability and promoting in fluid replacement. The beverage treatment that was delivered was in the form of a pre-mixed commercially available carbohydrate and electrolyte solution (Viper, Maximuscle, UK). For a schematic representation of the method used see Figure 1.

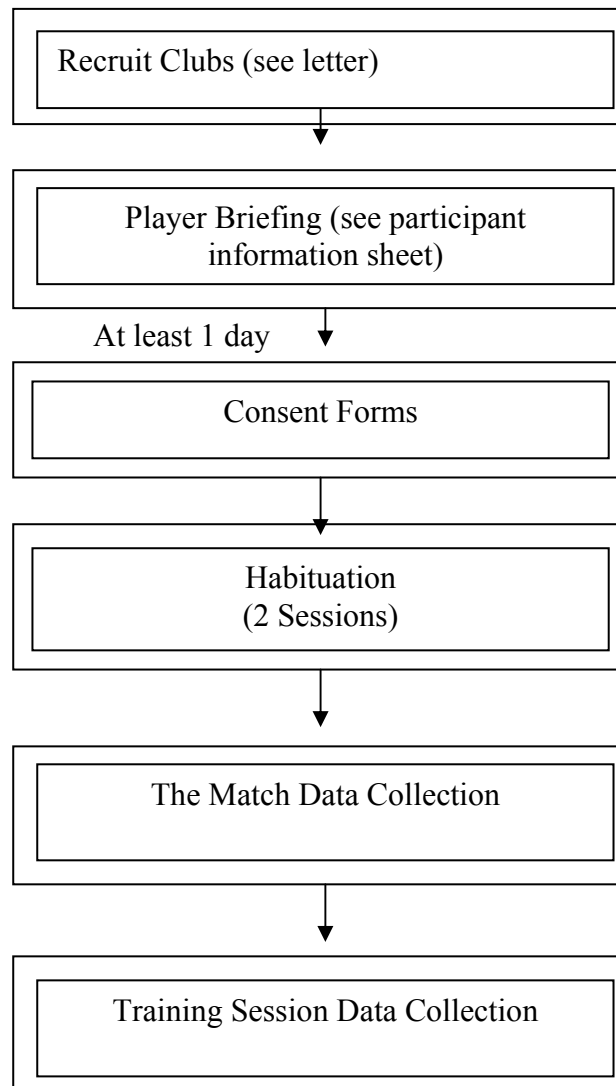


Figure 1. Schematic representation of methodology.

Sweat rate, Urine sampling, Sweat composition and Heart rate for both competition and training

Body mass was determined clothed in full cricket whites as well as in minimum clothing on analogue scales (Salter, England). Measurements were made when wearing minimal clothing pre and post match, as well as clothed during the

beginning and end of both the lunch and tea breaks. Food mass was measured on electronic digital top pan scales (Salter, England) to the nearest gram prior to consumption during both luncheon and tea breaks. An individually labelled sports drink bottle measured fluid input. Urine output was measured in a 500ml graduated measuring cylinder (Kartell, Italy). Subsequently a 25 ml aliquot of urine was pipetted into an inert polypropylene container. Prior to urine samples being collected on ice and the stored at -17°C before subsequent analysis of urine osmolarity with an osmometer (The Advanced Micro Osmometer 3300, Norwood Masseuses), urine colour was assessed. As urinary analysis requires technical expertise and requires a laboratory an attempt has been made by exercise physiologists and nutritionists in advising athletes to observe urine colour as an index of hydration status. This is because urine osmolality and urine colour are strongly related ($r = 0.82$, $P < 0.0001$; Armstrong, Herrera Soto, Hacker, Casa, Kavouras & Maresh, 1998). Therefore urine colour was used as an indication in the field of hydration status prior to the subsequent urine osmolarity analysis in the University of Chester Human Performance Laboratory. Holding each specimen container next to a colour scale (as used by Armstrong, 2000, appendix VIII), in a well-lit room, was the method used to assess urine colour. The colour scale consists of eight colours ranging from very pale yellow (#1) to a brownish green (#8). Faecal mass was determined by weighing subjects immediately pre and post defecation on the scales (Salter). Sweat rate was therefore estimated from the fluid balance profile as the change in body mass over time corrected for the water and food intake, urine and faecal loss by assigning a density of 1g.ml^{-1} to both water and urine i.e.

Sweat rate ($\text{kg}\cdot\text{hg}^{-1}$) = [change in body mass + drinks + food – urine – faeces]
(kg/time (hr) (Gore *et al.* 1993).

The composition of sweat has been examined using a variety of sampling methods (Shirreffs *et al.* 2006), with the crudest method simply catching each drip of sweat as it falls from the skin surface. The method mainly used is that of collecting sweat from a specific body region using a form of absorptive patch, this study replicated this popular method. This method was suggested by Shirreffs and colleagues (2006) by eliminating the problem of the evaporation of water from the skin surface. Prior to the start of both competition and training, two patches (Opsite Plus, Smith & Nephew, England) were placed on separate sites of the upper body and remained in place until conclusion of the exercise. After appropriate cleaning and preparation of the skin site both patches were placed on the right hand side of the body, because both subjects were right hand dominant. The first was placed on the upper back (on the shoulder blade, 2 cm above the inferior angle of the scapula) with the second on the forearm (equidistant between the head of the ulna and radius). After completion of the exercise (competition and training) the two patches were subsequently removed, placed in a sterile labelled container and diluted with 20 ml of deionised water. The sweat collected was analysed in the Somerset Scientific Services Laboratory for sodium (Na^+) and potassium (K^+) concentration by Inductively Coupled Plasma - Atomic Emission Spectrometry (Perkin Elmer 4300DV, Milano, Italy). The sweat samples were stored under the same protocol as the urine samples. Match and training heart rates were recorded for both subjects using recordable Polar Vantage NV hear rate monitors (Polar Electro Oy, Kempele, Finland). Heart rate was recorded following the methods of Gore *et al.* (1993). Once the raw data was collected it was subsequently downloaded to a personal computer using Polar

Advantage software (Polar Electro Oy) and then exported to Microsoft Excel Worksheet (Microsoft Corporation, UK).

All testing procedures were conducted under the British Association of Sport and Exercise Sciences (BASES) code of conduct (Appendix IX).

Data analysis

Generally in the field of sport and exercise physiology there is a tendency to avoid a single case study design, although under certain circumstances such as working with an elite athlete, this type of design is appropriate (Williams & Wragg, 2004). The data collected in this study is striving for an in-depth understanding of the fluid demands occurred during competition and training for each individual fast bowler.

For each individual subject the raw data (Appendix X) for competition and training will be reported, although certain variables (environmental conditions, heart rate, sweat rate, composition of sweat and drink volumes) will be reported as mean and standard deviations.

Chapter 4 – Results

Environmental conditions

The environmental conditions on the day of competition and training are summarised below (Table 2). The match day was distinguished by the highest mean WBGT index (22.9) and therefore labelled as a warm day. The day of training was distinguished by the highest mean WBGT index (19.5) and also labelled as a warm day (Met Office, 2007).

Table 2. Environmental conditions during competition and training. Values are the mean \pm standard deviation.

Day	Temperature Dry bulb (°C)	Temperature Wet Bulb (°C)	WBGT Index	Relative Humidity (%)
Match	22.9 \pm 1.1	17 \pm 0	22.9 \pm 0.4	53.1 \pm 7
Training	20.6 \pm 1.1	13.4 \pm 1.1	19.5 \pm 1.3	39.5 \pm 1.9

Competition heart rates

Due to the situation of the game (a declaration at lunch) the experimental team (consisting of the bowlers in this case study) did not commence bowling until after lunch (13.55 hrs) and finished bowling at the close of play (18.30 hrs). For the duration of this period a total of 60 overs were bowled in which eight wickets were taken for a total of 154 runs.

Subject 1

During the day of competition subject 1 bowled three spells totalling ten overs. The first spell lasted four overs the second spell, one over and the final spell five overs. The heart rate responses show that the bowler maintained a moderate intensity: the mean heart rate for the whole duration of competition, including drinks breaks and the tea break was 115 ± 25 beats \cdot min $^{-1}$ with a maximum rate of 182 beats \cdot min $^{-1}$. A more detailed analysis of heart rates during the three bowling spells show that the bowler maintained a moderate to high intensity effort (Figure 2). During the first bowling spell (4 overs) the mean heart rate was 139 ± 21 beats \cdot min $^{-1}$ with a maximum rate of 171 beats \cdot min $^{-1}$. During the second spell (1 over) the mean heart rate was 142 ± 28 beats \cdot min $^{-1}$ with a maximum rate of 177 beats \cdot min $^{-1}$. During the third spell (5 overs) the mean heart rate was 156 ± 21 beats \cdot min $^{-1}$ with a maximum rate of 182 beats \cdot min $^{-1}$.

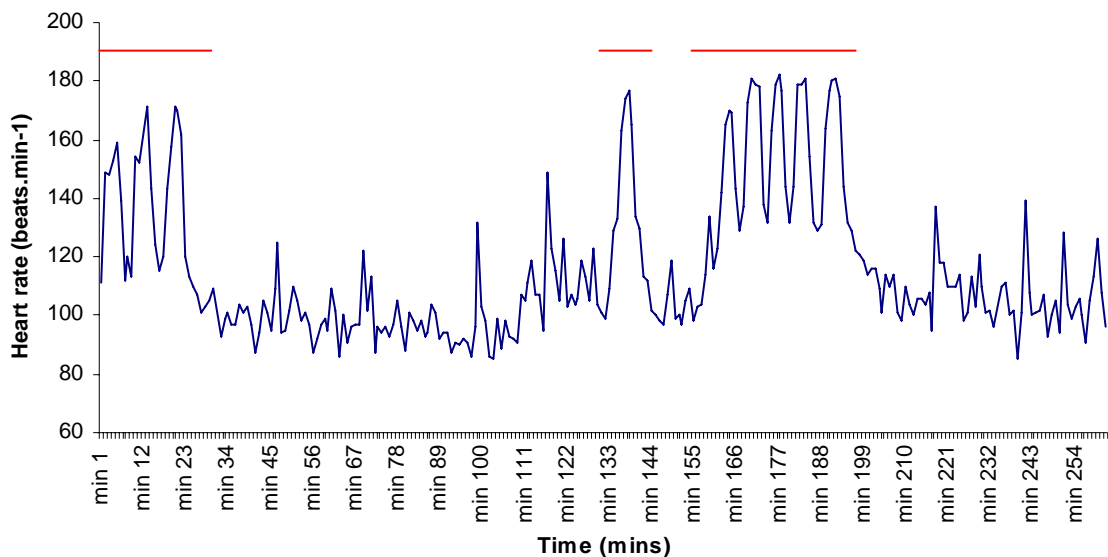


Figure 2. Heart rate profile for Subject 1. The solid lines indicate the bowling spells.

Subject 2

During the day of competition Subject 2 bowled one spell totalling five overs. The heart rate responses show that the bowler maintained a moderate intensity: the mean heart rate for the whole duration of competition, including drinks breaks and the tea break was 109 ± 22 beats \cdot min $^{-1}$ with a maximum rate of 181 beats \cdot min $^{-1}$. A more detailed analysis of heart rates during the bowling spell show that the bowler maintained a moderate to high intensity effort (Figure 3). During this bowling spell (5 overs) the mean heart rate was 146 ± 22 beats \cdot min $^{-1}$ with a maximum rate of 181 beats \cdot min $^{-1}$.

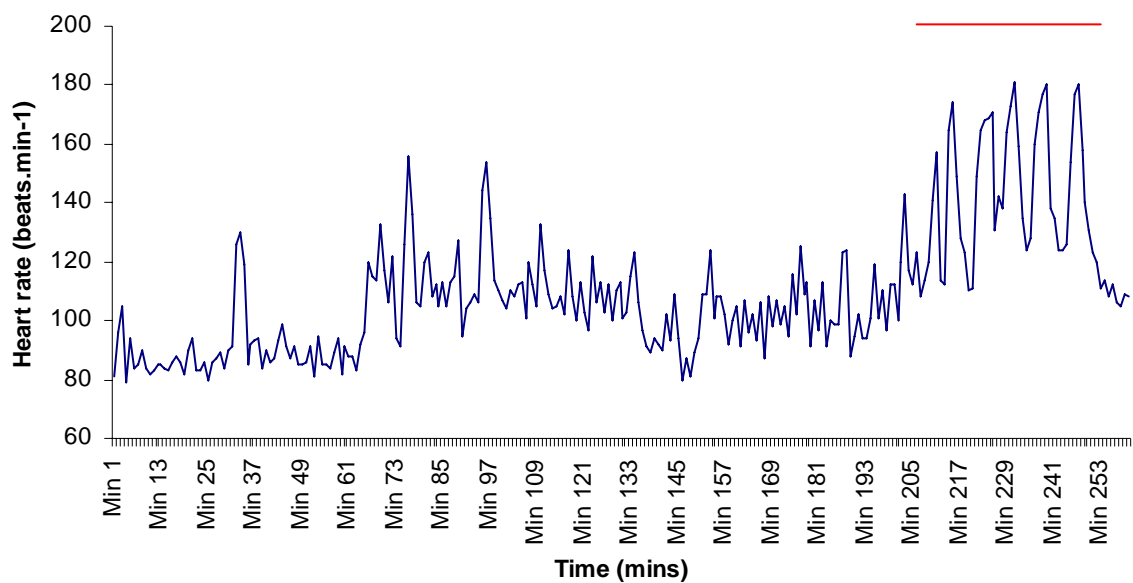


Figure 3. Heart rate profile for Subject 2. The solid line indicates the bowling spell.

Training heart rates

Subject 1

The heart rate responses show that the bowler maintained a moderate to high intensity effort during training: the mean heart rate for the whole duration of the session, including short rest periods and individual stretching, was 134 ± 32 beats \cdot min $^{-1}$ with a maximum heart rate of 181 beats \cdot min $^{-1}$. The mean heart rate recorded during training differed marginally from those recorded during competition (Figure 4).

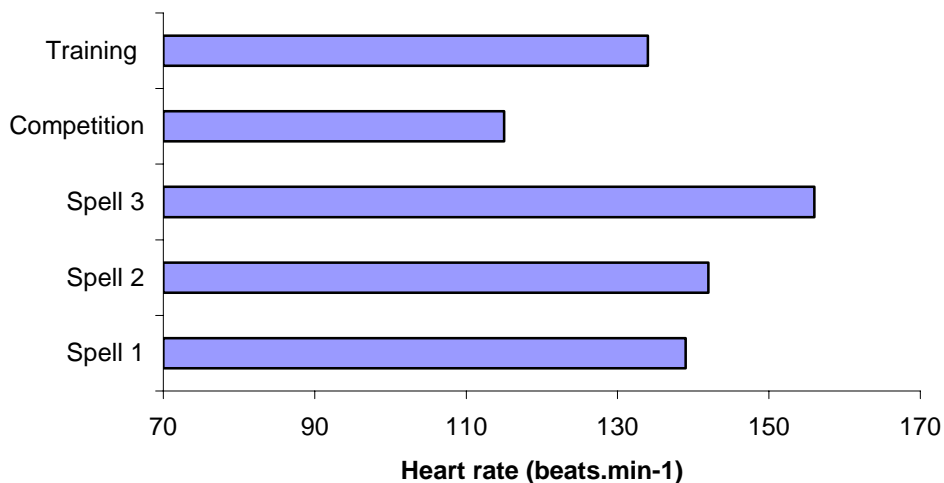


Figure 4. Mean heart rates for competition, bowling spell duration and training.

Subject 2

The heart rate responses show that the bowler maintained a moderate to high intensity effort during training: the mean heart rate for the whole duration of the session, including short rest periods and individual stretching, was 127 ± 29 beats \cdot min $^{-1}$ with a maximum heart rate of 186 beats \cdot min $^{-1}$. The mean heart rate

recorded during training differed marginally from what was recorded during competition (Figure 5).

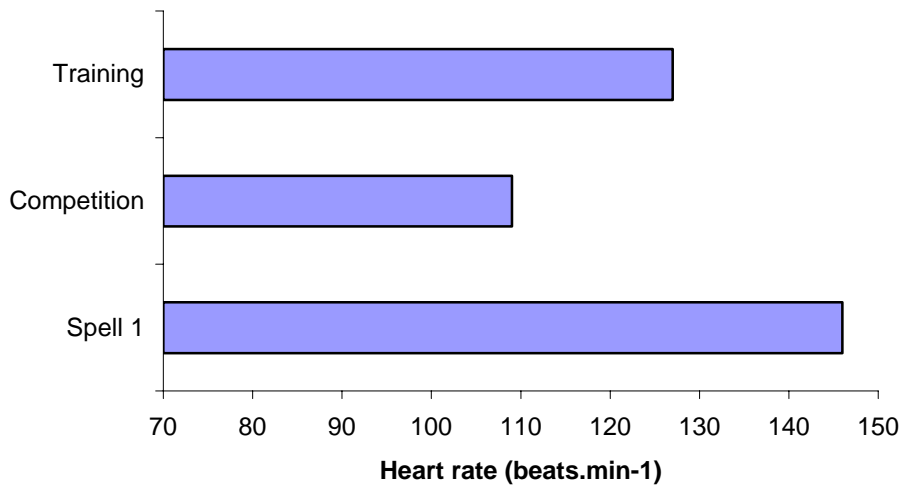


Figure 5. Mean heart rates for competition, bowling spell duration and training.

Competition sweat rates and fluid replacement

Subject 1

There was no reduction in body mass over the final two sessions of the day (between lunch and tea; between tea and the close of play). The subject drank a total of 4 litres of the commercially available sports drink (Maximuscle), consumed a food total of 0.93 kg and urinated a total of 1.6 litres. Therefore the calculated sweat rate was 0.73 kg.hr⁻¹ (p 49).

The volume of fluid consumed throughout the day totalled 4 litres over a course of 4.35 hrs, which equates to the consumption of 0.87 L.hr⁻¹. By utilising the calculations of Gore et al. (1993) in assigning a density of 1g to 1ml, Subject 1 replaced more than the volume of sweat lost during the previous hour of play (0.73 litres) by consuming 0.87 litres of fluid.

Subject 2

On the warm day, there was no reduction in body mass over the final two sessions of the day (as detailed above). The subject drank a total of 2.9 litres of the commercially available sports drink (Maximuscle) consumed a food total of 0.93 kg and urinated a total of 0.38 litres. Therefore the calculated sweat rate was $0.93 \text{ kg}\cdot\text{hr}^{-1}$.

The volume of fluid consumed throughout the day totalled 2.9 litres over a course of 4.35 hrs, which equates to the consumption of $0.63 \text{ L}\cdot\text{hr}^{-1}$. By utilising the calculations of Gore et al. (1993), Subject 2 failed to replace more than the volume of sweat lost during the previous hour of play (0.93 litres) by consuming 0.63 litres of fluid.

Training sweat rates

Subject 1

During the training session there was a reduction in body mass of 0.5 kg. This is equivalent to a level of dehydration of 0.67 % of the pre-training body mass. The subject did not urinate or consume any fluid during the training session therefore the calculated sweat rate was $0.2 \text{ kg}\cdot\text{hr}^{-1}$.

Subject 2

During the training session there was a reduction in body mass of 0.5 kg. This is equivalent to a level of dehydration of 0.66% of the pre-training body mass. The subject did not urinate or consume any fluid during the training session therefore the calculated sweat rate was $0.2 \text{ kg}\cdot\text{hr}^{-1}$.

Given the same environmental conditions for both training and competition the calculated sweat rates predominantly reflect the differences in workload and fluid intake for both subjects (Figure 6).

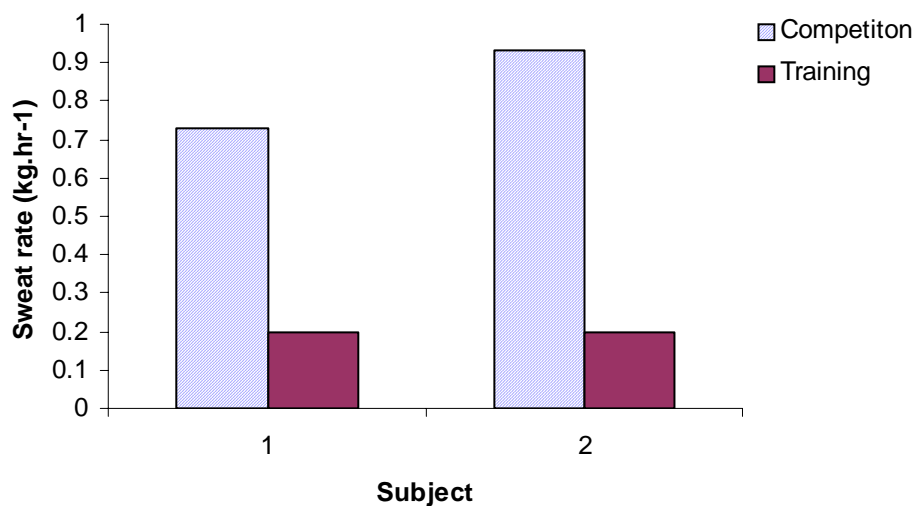


Figure 6. Sweat rates during both competition and training.

Competition urinary volume, colour and osmolality

Subject 1

During each scheduled break of play (lunch, tea and close) urine was passed totalling 1.6 L. All urine samples were also immediately analysed for urine colour. Prior to commencing bowling at the end of lunch a total of 0.22 L was passed, with a urine colour of 2. During the tea break 0.375 L of urine was passed with a colour of 2 and at the close of play the subject passed urine twice totalling 1.01 L, the first sample was 0.51 and the second 0.50 L respectively. Both of these samples provided a urine colour of 1.

Urinary osmolality shows that prior to commencing bowling osmolality was higher than at tea and at the close of play. The urine osmolality at lunch was 331 mOsmol \cdot kg $^{-1}$, at tea 327 mOsmol \cdot kg $^{-1}$ and at the close of play the first of the two urine samples was 60 mOsmol \cdot kg $^{-1}$ (Figure 7).

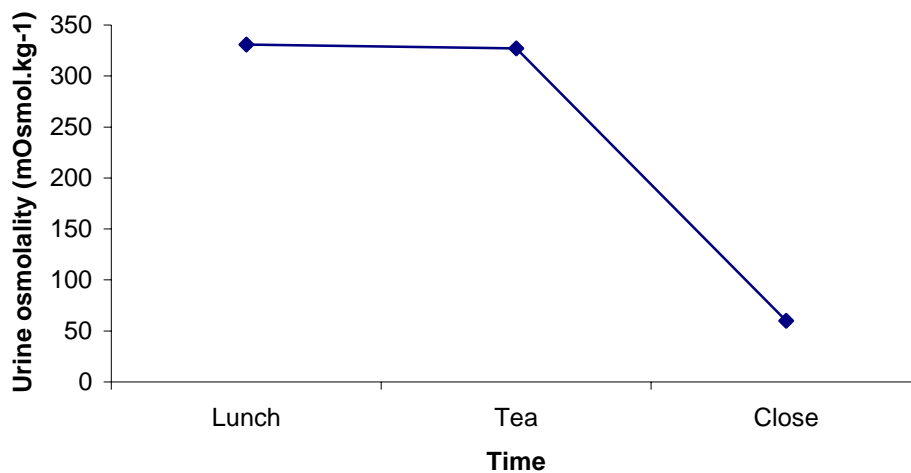


Figure 7. Urine osmolality at each scheduled break in play during competition

Subject 2

During each scheduled break of play urine was passed totalling 0.38 L. All urine samples were also immediately analysed for urine colour. Prior to commencing bowling at the end of lunch a total of 0.145 L was passed, with a urine colour of 4. During the tea break 0.12 L of urine was passed with a colour of 4 and at the close of play the subject passed 0.115 L of urine with a urine colour of 4.

Urinary osmolality shows that for the duration of the day, the change in osmolality was minimal. The urine osmolality at lunch was 842 mOsmol·kg⁻¹, at tea 886 mOsmol·kg⁻¹ and at the close of play the first of the two urine samples was 819 mOsmol·kg⁻¹ (Figure 8).

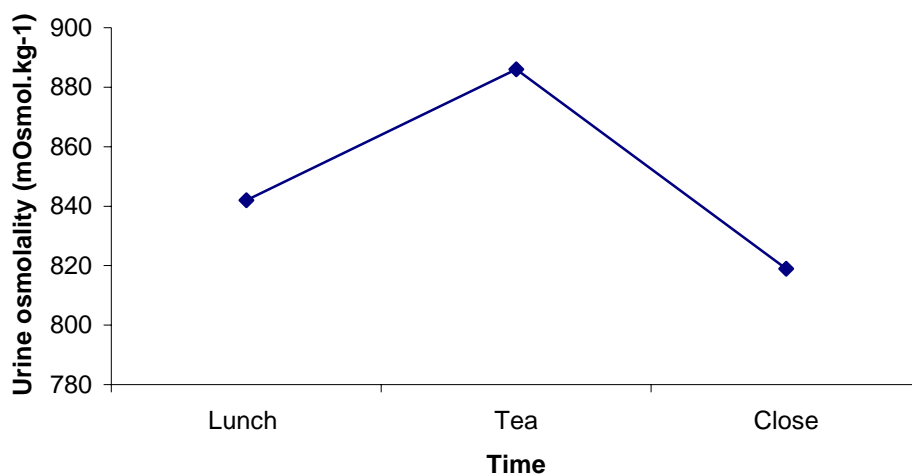


Figure 8. Urine osmolality at each scheduled break in play during competition

Training urinary volume and osmolality

Subject 1

After the conclusion of training 0.145 L of urine was passed, with a urine colour of 3. The urine osmolality for this sample was $730 \text{ mOsmol}\cdot\text{kg}^{-1}$.

Subject 2

No urine was passed during or at the conclusion of the training session, thus no values have been reported.

Competition sweat composition

Subject 1

The mean sodium (Na^+) concentration of sweat measured from the two sites of the body was $37.8 \pm 26.9 \text{ mmol}\cdot\text{l}^{-1}$. The mean sweat potassium (K^+) concentration from the same two sites was $3.6 \pm 1.4 \text{ mmol}\cdot\text{l}^{-1}$.

Subject 2

The mean Na^+ concentration of sweat measured was $16.8 \pm 2.1 \text{ mmol}\cdot\text{l}^{-1}$. The mean sweat K^+ concentration was $2.1 \pm 0.7 \text{ mmol}\cdot\text{l}^{-1}$.

Training sweat composition

Subject 1

The mean Na⁺ concentration of sweat measured was 45.7 ± 34.3 mmol·l⁻¹. The mean sweat K⁺ concentration was 2.2 ± 0.4 mmol·l⁻¹.

Subject 2

The mean Na⁺ concentration of sweat measured was 36.7 ± 22.2 mmol·l⁻¹. The mean sweat K⁺ concentration was 2.5 ± 0.5 mmol·l⁻¹.

Sweat composition summary data is shown below for both subjects for competition and training (Table 3).

Table 3. Sweat sodium and potassium concentrations for each subject during both competition and training. Values are mean \pm standard deviation.

	Competition		Training	
	Sodium (mmol·l ⁻¹)	Potassium (mmol·l ⁻¹)	Sodium (mmol·l ⁻¹)	Potassium (mmol·l ⁻¹)
Subject 1	37.8 ± 26.9	3.6 ± 1.4	45.7 ± 34.3	2.2 ± 0.4
Subject 2	16.8 ± 2.1	2.1 ± 0.7	36.7 ± 22.2	2.5 ± 0.5

Chapter 5 – Discussion

Environmental conditions

The environmental conditions measured during this study are categorised as falling under the normal range under which cricket is played in England. It is suggested (Sports Medicine Australia, 2007) that Wet Bulb Globe Temperature (WBGT) is the best measure of heat strain currently available as it accounts for the levels of humidity, radiation, wind movement and ambient temperature. Using the WBGT index the environmental conditions under which the subjects participated were classified as having a moderate risk of heat injury (between 18-22°C). Although during competition (22.9°C) a WBGT index encroached upon having a high risk of heat injury (23-28°C)(Sports Medicine Australia, 2007).

The purposes of heat stress indices are to take into account of all the factors contributing to thermal stress and thus enabling a decision to be made upon the conditions being too hot for safety or comfort (Gore et al. 1993). An ideal heat stress index should not only assess the environment, as does the WBGT, but also take into account clothing, exercise intensity and the physiological characteristics of the individual (Gore et al. 1993). This method (WBGT) of assessing the environment has attracted some criticism (Morante & Brotherhood, 2007; Cooper, Ferrara, & Broglio, 2006). However it is still the most widely accepted measure of environmental conditions (Cooper et al. 2006). This may be an appropriate reference point for the recognition and management of potentially dangerous heat situations (Sports Medicine Australia, 2007). These suggestions may need further consideration, in a more mild environment such as in England.

Heart rate

The measurement of heart rate is the only means currently available for estimating the exercise intensity during cricket (Noakes & Durandt, 2000). This measurement provides a useful index of the overall physiological strain, moreover in highlighting the demands placed upon a fast bowler commencing a bowling spell. The mean heart rates recorded during competitive cricket in this present study were 112 beats·min⁻¹ (Figure 4 & 5). Similar findings of 116 beats·min⁻¹ in heart rates were reported by Gore and colleagues (1993), during simulated cricket. The results from this present study and that of Gore et al. (1993) show that mean heart rates during a day's cricket seldom rise above 130 beats·min⁻¹. However with closer analysis of heart rates during a bowling spell, a bowler frequently reaches ~180 beats·min⁻¹, which is similar to what is experienced by marathon runners (Noakes & Durandt, 2000), therefore identifying the high physical demand placed upon fast bowlers. Unfortunately, research conducted by Gore et al. (1993) was the first and only study to be published providing heart rate responses of fast bowling, thus comparisons to other sports have been made. The overall mean heart rates are significantly lower than what is experienced in competitive rugby league (166 beats·min⁻¹, Coutts, Raeburn & Abt, 2003), futsal (176 beats·min⁻¹, Barbero-Alvarez, Soto, Barbero-Alvarez & Granda-Vera, 2007) and tennis (140-160 beats·min⁻¹, Kovacs, 2007; Fernandez, Mendez-Villanueva & Pluim, 2006) respectively.

The mean heart rates recorded during an intense training session in this study were 131 beats·min⁻¹. Unfortunately there is a lack of research focusing upon heart rate responses during cricket training thus further comparisons to identify the physiological demands will be conducted against soccer in both the field and the

laboratory setting. Compared to soccer in the field the mean heart rates were similar ($136 \text{ beats} \cdot \text{min}^{-1}$, Shirreffs et al. 2005) although in the laboratory setting the heart rates were significantly lower ($165 \text{ beats} \cdot \text{min}^{-1}$, Drust, Reilly & Cable, 2000).

From this it is clear that fast bowlers must be well conditioned to cope with the extensive demands of repetitive high intensity exercise (Brearley & Montgomery, 2002) and it would be beneficial to have these athletes working at higher heart rates, interspersed with lower rates. This would attempt to mimic the cardiovascular stress a fast bowler faces in a match situation.

Sweat rate and fluid replacement

The mean sweat rates during the day of competition for each subject were $0.73 \text{ kg} \cdot \text{hr}^{-1}$ and $0.93 \text{ kg} \cdot \text{hr}^{-1}$ respectively (Figure 6). In comparison to previous research (Gore et al. 1993; Brearley & Montgomery, 2002; Soo & Naughton, 2007) under similar environmental conditions (22.1 and 24.5 WBGT) sweat rates for these fast bowlers are similar to what were previously reported $0.70 \text{ kg} \cdot \text{hr}^{-1}$, $0.80 \text{ kg} \cdot \text{hr}^{-1}$ and $0.71 \text{ kg} \cdot \text{hr}^{-1}$ respectively. Making direct comparisons is difficult because of the different exercise intensities inherent between bowling in “unlimited overs” (e.g. test match) and “limited overs” (e.g. one-day) cricket.

The mean sweat rates during the training session for both subjects were $0.20 \text{ kg} \cdot \text{hr}^{-1}$ (Figure 6). In comparison to earlier research (Burke & Austin, 2006) the current sweat rates from these fast bowlers is significantly lower $1.20 \text{ kg} \cdot \text{hr}^{-1}$, although a direct comparison cannot be made, as the environmental conditions were significantly higher (29°C , 50% relative humidity).

Little research (Gore et al. 1993; Brearley & Montgomery, 2002; Burke & Austin, 2006) has been conducted highlighting the sweat rates of fast bowlers. In order to gain a greater understanding of sweat rates experienced in both competition and training, other sports will be discussed to quantify fluid balance. In comparison to sweat rates in competitive soccer ($1.21 \text{ kg}\cdot\text{hr}^{-1}$) and basketball ($1.60 \text{ kg}\cdot\text{hr}^{-1}$) respectively, the mean sweat rates are significantly lower (Broad, Burke, Cox, Heeley & Riley, 1996; Burke & Hawley, 1997). In comparison to sweat rates recorded during training in soccer ($0.99 \text{ kg}\cdot\text{hr}^{-1}$), basketball ($1.37 \text{ kg}\cdot\text{hr}^{-1}$) and American football ($2.14 \text{ kg}\cdot\text{hr}^{-1}$) respectively, the mean sweat rates are significantly lower (all data from Broad et al. 1996; Burke & Hawley, 1997). For all comparative data the environmental conditions were described as having a temperature $>20^{\circ}\text{C}$ with the exception of the American football data (28.4°C , 64.9% relative humidity and 34.5°C , 43% relative humidity), thus reducing the validity of making direct comparisons to what was experienced during the current cricket practice.

The type of exercise session undertaken by cricketers is an important factor in determining sweat loss rates. Greater sweat rates were found during competition with sweat rates during training significantly lower. It is suggested (Broad et al. 1996) that these differences are most likely due to the varying intensities of exercise rather than the environmental conditions. This suggestion can be supported from the current analysis of heart rates recorded during bowling in competition and training (Figure 4 & 5). These findings are further supported with the evidence from Woolford and Angove (1991)(cited in Broad et al. 1996), who found that time spent at high intensity in netball matches was greater than during training sessions.

At the end of four hours and thirty-five minutes of cricket, the level of dehydration recorded for both subjects was insignificant. Subject 1 consumed $0.87\text{L}\cdot\text{hr}^{-1}$ of fluid

and Subject 2 $0.63\text{L}\cdot\text{hr}^{-1}$ respectively. In comparison to fluid consumption in elite women's cricket ($0.25\text{L}\cdot\text{hr}^{-1}$, Soo & Naughton, 2007) subjects consumed significantly more. The volume of voluntary fluid intake for male athletes competing in Australian rules football ($0.87\text{L}\cdot\text{hr}^{-1}$) and soccer ($0.52\text{L}\cdot\text{hr}^{-1}$) are similar (data provided by Burke, 2007). Both subjects were able to closely match their fluid intake to the volumes of sweat lost in the previous hours of play and at all drinks breaks. By utilising Gore et al. (1993) calculations in assigning a density of 1g to 1ml , calculations can be made in providing information concerning fluid balance. Subject 1 was able replace a greater amount of fluid than that perspired $0.73\text{L}\cdot\text{hr}^{-1}$, where as Subject 2 was unable to match his sweat rate $0.93\text{L}\cdot\text{hr}^{-1}$.

At the end of one hundred and fifty minutes of cricket training the mean level of dehydration was only -0.66% of pre training body mass. As neither subject consumed any fluid, the potential for dehydration was greater than if any fluid was consumed. In comparison to levels of dehydration during training observed in cricket (-1.00% , Burke & Austin, 2006) and other team sports; American football (-1.20%), rugby league (-0.70%) and soccer (-1.59 , -1.40%) respectively, the levels of dehydration are all greater (data provided from Burke, 2007).

One possible reason why only a small level of dehydration was observed during training and nothing during competition is that this study used analogue scales where small changes cannot be clearly observed, where as when using a digital model these small changes can be identified more easily.

Renal changes

Besides the small changes in body mass, urinary variables have been suggested (Shirreffs & Maughan, 1998; Oppliger & Bartok, 2002; Kutlu & Guler, 2006) to be good indicators in identifying hydration status. The variables used in this study (osmolality and colour) are widely used for this purpose. Under normal conditions first morning urine is used to provide a baseline measurement of hydration status (Shirreffs & Maughan, 1998) although due to the commencement of bowling after lunch this baseline measurement commenced during the lunch break. The results for Subject 1 at each time period were; at lunch 331 mOsmol·kg⁻¹, at tea 327 mOsmol·kg⁻¹ and at the close of play the urine sample was 60 mOsmol·kg⁻¹. The results for Subject 2 were; at lunch 842 mOsmol·kg⁻¹, at tea 886 mOsmol·kg⁻¹ and at the close of play the urine sample was 819 mOsmol·kg⁻¹. Oppliger and Bartok (2002) suggest that urine osmolality of less than 500 mOsmol·kg⁻¹ reflects a euhydrated state. Shirreffs and Maughan (1998) have also shown that an osmolality greater than 900 mOsmol·kg⁻¹ can be taken as an indication consistent with dehydration. The urine osmolality values recorded show that Subject 1 was able to stay in a euhydrated state, as the urine osmolality remained <500 mOsmol.kg⁻¹. Subject 2's urine osmolality fell between both classification points and therefore was neither euhydrated or dehydrated although these values recorded were close to the upper limit set (Shirreffs and Maughan 1998) consistent with dehydration.

Assessing the colour of urine is a simple and inexpensive method of assessing hydration status (Oppliger & Bartok, 2002). Urine dark in colour is generally considered a sign of fluid deficit where as a pale yellow urine is considered a sign of being sufficiently hydrated. Armstrong et al. (1994) determined that a urine colour

of >3 on the colour scale represents a state of dehydration. More recently research by Oppliger and Bartok (2002) stated that a urine colour of ≥ 4 is consistent with dehydration. The results from this study show that at each time point Subject 1 was able to maintain a state of euhydration as at lunch the urine colour was 2, tea 2 and at the close of play the urine colour was 1 respectively. Subject 2's urine colour at all time points was 4 and therefore becomes classified as being in a state of dehydration.

At the conclusion of training, Subject 1 was the only subject to pass urine. The urine osmolarity was $730 \text{ mOsmol} \cdot \text{kg}^{-1}$. By using the classification guidelines (Shirreffs & Maughan, 1998; Oppliger & Bartok, 2002) it can be identified that Subject 1 was neither euhydrated nor dehydrated. The urine sample provided a urine colour of 4 and therefore classifies Subject 1 as being in a state of dehydration.

The osmolality and colour results in this study were in good agreement with each other and with the related literature. Because of the high correlation between osmolality and colour these methods can be used as simple and inexpensive methods in assessing hydration status for fast bowlers.

Sweat composition

It is important to remember that the data collected concerning sweat composition has been determined from localised collection of sweat from two sites on the upper body. The mean sodium (Na^+) composition for Subject 1 and 2 during competition was $37.8 \pm 26.9 \text{ mmol} \cdot \text{l}^{-1}$ and $16.8 \pm 2.1 \text{ mmol} \cdot \text{l}^{-1}$, respectively. The mean potassium (K^+) composition for both subjects was $3.6 \pm 1.4 \text{ mmol} \cdot \text{l}^{-1}$ and $2.1 \pm 0.7 \text{ mmol} \cdot \text{l}^{-1}$,

respectively. Unfortunately there is no data published concerning sodium and potassium losses during competition.

The mean Na⁺ composition for the both subjects during training was 45.7 ± 34.3 mmol·l⁻¹ and 36.7 ± 22.2 mmol·l⁻¹, respectively. The mean K⁺ composition for both subjects was 2.2 ± 0.4 mmol·l⁻¹ and 2.5 ± 0.5 mmol·l⁻¹, respectively. Unfortunately there is limited data to provide a comparison to team sports although research by Shirreffs et al. (2005) found mean Na⁺ and K⁺ compositions during training in soccer of 30.2 ± 18.8 and 3.58 ± 0.56 , respectively. Laboratory research by Shirreffs and Maughan (1997) produced normal values for sweat electrolyte composition. The mean and standard deviation values for Na⁺ of 50.8 ± 16.5 and K⁺ of 4.8 ± 1.6 respectively. The authors (Shirreffs & Maughan, 1997) also produced normative ranges (Na⁺ 35.2-81.0 and K⁺ 2.7-6.8, respectively). The sweat compositions in the two fast bowlers tested were within the normal ranges as suggested by Shirreffs and Maughan (1997). The results obtained using this method for sweat collection from exercising cricketers demonstrate that it is possible to obtain reliable and reproducible measures of sweat composition.

Research limitations and further research

The main limitation to this current study was that the sample size was very small. The influence of the environmental conditions, standard of the opposition and fitness of the participants may also be significant. Although it would have been advantageous to investigate more competitive games, due to logistical difficulties and the nature of the protocol used, this was not practical. Therefore, generalisation of the current findings to fast bowlers of different standards (e.g. elite and amateur)

and under different environmental conditions may not be applicable. Further studies should be conducted to identify the physiological strain placed upon fast bowlers during a whole season, rather than just an individual match and training session, to gain a better understanding of how well players respond to these demands and modify drinking practices.

Conclusion

The results from this present study show that under warm environmental conditions (WBGT index 22.9°C and 19.5°C, respectively) one of the two sub-elite fast bowlers did not drink sufficient fluid during competition and both subjects failed to replace their sweat loss during training. This was further reflected in the analysis of urine osmolality, in which for the duration of competition produced a urine osmolarity of $\sim 850 \text{ mOsmol}\cdot\text{kg}^{-1}$, which is close to the suggested values ($>900 \text{ mOsmol}\cdot\text{kg}^{-1}$, Shirreffs & Maughan, 1998) consistent with dehydration. Although one of the two bowlers was able to closely match fluid intake with sweat loss the suggested guidelines (ACSM, 1997; Burke, 1997; Burke & Hawley, 1997; NATA, 2000) should be considered in providing general guidelines for cricketers performing in thermally stressful environments. The mean values of sweat rate and fluid consumption hide the large inter-individual differences in both sweating response and drinking practices of the bowlers. These measurements support the suggestions of Burke and Austin (2006), that by allowing a cricket club to individualise the advice and support it gives to its players, with respect to a hydration strategy to minimise the reductions in competition and training.

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Appendix I – First study to examine urinary indices of hydration status

Research conducted by Armstrong and co-workers (1994) examined urinary indices of hydration status. Unfortunately there is no universally accepted method for the determinations of hydration status as the interpretation of urinary measurements are difficult. In an effort to simplify hydration testing experts have advised athletes to observe urine colour as an index of hydration status (Armstrong *et al.* 1994). Therefore the purpose of this study was to utilise a novel urine colour scale and examine corresponding urinary measurements, to identify if urine colour indicates hydration status accurately, as verified by urine osmolality to clarify its use in research.

There were three separate studies in this investigation, involving different research designs. Studies A, B and C (detailed subsequently) represented a variety of factors (environmental conditions, gender, heat acclimatisation, bladder void, rest and exercise), thus increasing the scenarios to which urine colour might be applied as an index of hydration.

Study A: Twenty-three male college students volunteered for this study. A 30-day activity and heat exposure diary was recorded, indicating that subjects ranged from unfit to very fit and were not heat acclimatised. Subjects drank two glasses of water (≥ 237 ml each) prior to going to sleep (~9 hours before testing) and after waking the day of the test to decrease the likely hood of being hypohydrated. First morning urine was collected and upon reporting to the laboratory (07:30 hrs). This specimen was analysed for urine colour and osmolality. Subjects then consumed water (115 ml) and reclined in an air-conditioned room (22°C) for 4 hours. Subjects provided a final urine sample, to allow measurement of 4-hr urine volume.

Study B: Eleven male college students volunteered for this study. An activity and heat exposure diary (See study A) indicated that physical fitness ranged from unfit to fit and were not heat acclimatised. Subjects followed instructions regarding water intake, which was identical, to what was described in Study A. Subjects reported to the laboratory between 08:00 and 14:00 hrs the day of testing. Pre-test urine typically represented the second bladder void of the day. This specimen and the final urine specimen (5 min post-exercise) was analysed for urine colour and osmolality.

Subjects were required to wear a cardiometer and insert a rectal probe. Subjects wore a specially designed clothing ensemble allowing only the face and hands to be exposed to the air. Subjects entered an environmental chamber ($32.2 \pm 0.4^{\circ}\text{C}$, $57 \pm 19\%$ relative humidity) and stood for 15 minutes to begin acclimatisation. Each hour subject were required to walk for 50 minutes ($4 \text{ km}\cdot\text{hr}^{-1}$, 0% grade), which was followed by 10 minutes of standing rest for a total of 3 hours. During exercise subjects consumed only enough water to wet the mouth.

Study C: Twenty subjects (8 female, 12 male) who were highly trained member of intercollege tennis teams (National Collegiate Athletic Association, Division 1), who were heat acclimatised by virtue of regular strenuous training were recruited for this study. Subject played three strenuous tennis matches on each of 3 consecutive days, beginning at 08:00 hrs (singles), 12:00 hrs (singles) and 16:00 hrs (doubles) in hot humid conditions ($27.2 - 33.7^{\circ}\text{C}$, $57 - 71\%$ relative humidity). Subjects consumed food and fluid ad libitum during matches, between matches and during non-testing hours (18:00 – 08:00 hrs). Prior and after each match urine samples were collected, and subsequently analysed for urine colour and specific gravity.

Data in Studies A, B and C incorporated calculations of linear regression and Pearson product correlation coefficients between all variables. Changes in urine during exercise in Study B were evaluated for significance using a Students' t-test. In Study C a two-way multivariate analysis of variance (MANOVA) was used to assess differences.

The main finding from study A was that there was a significant relationship between urine colour and osmolality ($r = 0.62$, $p < 0.01$). Study B also found a significant relationship between urine colour and osmolality ($r = 0.92$, $p < 0.0001$) although this relationship is stronger. Significant relationships were also found in Study C, although as the variables recorded have little concern to this current research paper they have been ignored.

Considering these findings Armstrong et al. (1994) concluded in recommending that urine colour may be utilised as a meaningful index of hydration status when measurements of urine osmolality are not possible or practical (e.g. athletic teams or field studies).

Appendix II – Letter of approval for the experimental procedures obtained from the centre for Public Health Research Ethics Committee of the University of Chester

James Bray

04 August 2010

Dear James

Study title: Are cricket fast bowlers in danger of dehydration?
SREC reference: 156/07/JB/CENS
Version number: 2

Thank you for sending the above-named application to the School of Applied and Health Sciences Research Ethics Committee for review.

The application has been considered on behalf of the Committee by Dave Smith as Lead Reviewer and reported to the School Research Ethics Committee.

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form and supporting documentation.

The favourable opinion is given provided that you comply with the conditions set out in the attached document. You are advised to study the conditions carefully.

The final list of documents reviewed and approved by the Committee is as follows:

Document	Version	Date
Application Form	1	May 2007
Participant Information Sheet	2	June 2007
Participant Consent Form	2	June 2007
Health Screening Questionnaire	2	June 2007
Protocols for data collection	2	June 2007
Letter of invitation to participants	1	May 2007

With the Committee's best wishes for the success of this project.

Yours sincerely,

Stephen Fallows

Chair, School Research Ethics Committee

Enclosures Standard conditions of approval.

c.c. Supervisor
SREC Representative

Appendix III – Letter of recruitment to Somerset County Cricket Club

Mr J W Bray



Mr A Hurry,
The County Ground,
St. James's Street,
Taunton,
Somerset,
TA1 1JT

04 July 2007

Dear Mr Hurry,

Please let me introduce myself, my name is James Bray and I am reading for a Masters in Exercise and Nutrition science at the University of Chester. As part of this degree, I am required to undertake an independent research project. In this connection I will be investigating the potential benefits of an adequate fluid intake and choice of beverage for fast bowlers.

I am writing to seek the assistance of Somerset County Cricket Club in a proposed research project.

The purpose of this study is to identify the importance of hydration for fast bowlers conducted during actual match conditions during an English summer. This study will compare differing forms of hydration (water, carbohydrate and a carbohydrate and electrolyte mix) in identifying the best to maintain optimal hydration levels and am seeking elite fast bowlers to participate in this study.

If you or any of your coaching staff are potentially interested in becoming involved in this study then please contact me and further information will be provided.

Enclosed is a participant information sheet detailing in brief the testing procedures.

Thank you for your time and kind regards

James W Bray BSc (Hons)

Appendix IV – Participant information sheet

Participant Information Sheet

The Physiological and Hydrational Demands of Fast Bowling in Cricket

You are being invited to take part in a research study. Before you decide to participate it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Please do not hesitate to ask if you would like more information about any aspect of the study or if anything is unclear. Take time to decide whether or not you wish to take part.

What is the purpose of the study?

The purpose of this study is to identify the importance of hydration for fast bowlers in cricket conducted during actual match conditions during an English summer. This study will compare differing forms of hydration (water, CHO, CHO and electrolytes) in identifying the best to maintain optimal hydration levels.

This study will take place over the summer months spanning a cricket season. Participants will be required to attend the cricket ground on seven separate occasions.

Why have I been chosen?

The test procedures have been designed to assess the importance of adequate hydration for fast bowlers. You have been asked to participate in this study as a fast bowler competing at an elite level.

Do I have to take part?

It is entirely up to you if you wish to participate in this study. If you decide to participate you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect the standard of care you receive in any way.

What will happen to me if I take part?

You will be required to attend your cricket ground on seven separate occasions.

The first two sessions will involve the recording of your personal details, including; age, height and weight. These two sessions will also provide by the habituation of heart rate monitoring equipment and sweat patches.

During these two familiarisation sessions you the subject will be required to bowl as part of a routine net session.

In the next two subsequent sessions you will be required to participate and bowl in two actual games. The data obtained from these two matches will provide appropriate information to the following three simulated match situations enabling a specific drinking protocol to be derived.

The results of each trial will be recorded but will not be disclosed to you until the completion of the final test.

In all testing sessions the following measurements will be taken:

- 1st morning urine
- Urine prior to the commencement of stepping out on to the cricket ground
- Heart rate (this will involve wearing a Polar heart rate monitor)
- Sweat composition (this will involve wearing two sweat patches)
- Percentage of fluid lost through sweating in relation to body weight

If you decide to take part, you will be given this information sheet to keep and asked to sign a consent form. Before each testing session you will also be asked to complete a short health-screening questionnaire. There will be someone present to answer any questions or concerns you may have in connection with these.

What are the possible disadvantages and risks of taking part?

It is possible that when undertaking the testing sessions you may experience some physical discomfort due to the effort required. These feelings should be familiar to you through your normal fast bowling experiences.

What are the possible benefits of taking part?

Each participant will receive a personal report following completion of the trials detailing anthropometric measurements, sweat rates and electrolyte concentration lost in sweat. This will enable each individual to apply fluid loss data to an adequate rehydration scheme.

By taking part, you will also be contributing to the development of knowledge concerning hydration for cricket fast bowlers. This will hopefully benefit you and other athletes in the future.

What if something goes wrong?

If you wish to complain or have any concerns about any aspect of the way you have been approached or treated during the course of this study please contact Professor Sarah Andrew, Dean of the School of Applied and Health

Sciences, University of Chester, Chester, CH1 4BJ, telephone: 01244 513055.

If you are harmed by taking part in this research project, there are no special compensations arrangements. If you are harmed due to someone's negligence (but not otherwise), then you may have grounds for legal action but you may have to pay for this.

Will my taking part in the study be kept confidential?

All information collected about you during the course of the research will be kept strictly confidential so that only the researcher carrying out the research will have access to such information.

What will happen to the results of the research study?

The results will be written up into a report as part of an MSc thesis and also possibly used for and in a research publication. Individuals who participate will not be identified in any subsequent report or publication.

Who is organising and funding the research?

The University of Chester will provide and assist in the funding of this research project.

Who may I contact for further information?

If you would like further information about the research before you decide whether or not to participate, please contact:

James W Bray
Centre for Exercise and Nutrition science
University of Chester
Parkgate Road
Chester
CH1 4BJ
Tel. 01244 513402
Email: 0617429@chester.ac.uk

Thank you for your interest in this research.

Appendix V – Example consent form

Consent form

Title of Project: The physiological and hydrational demands of fast bowling in cricket.

Name of Researcher: James W Bray

Please tick box

1. I confirm that I have read and understand the information sheet datedfor the above study and have had the opportunity to ask questions.
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason and without my legal rights being affected.
3. I agree to take part in the above study.

_____	_____	_____
Name of Participant	Date	Signature
_____	_____	_____
Name of Person taking consent (if different from researcher)	Date	Signature
_____	_____	_____
Researcher	Date	Signature

1 for participant; 1 for researcher

Appendix VI – Example medical history questionnaire



University of
Chester

Health Screening Questionnaire

The physiological and hydrational demands of fast bowling in cricket

Researcher : *James W Bray*

Name: _____

Test date: _____

Address: _____

Contact number: _____

Date of birth: _____

In order to ensure that this study is as safe and accurate as possible, it is important that each potential participant is screened for any factors that may influence the study. Please circle your answer to the following questions:

1. Has your doctor ever said that you have a heart condition *and* that you should only perform physical activity recommended by a doctor? YES/NO
2. Do you feel pain in the chest when you perform physical activity? YES/NO
3. In the past month, have you had chest pain when you were not performing physical activity? YES/NO
4. In the past year, have you experienced any heat illness? YES/NO
5. Do you lose your balance because of dizziness *or* do you ever lose consciousness? YES/NO

YES/NO

6. Do you have bone or joint problems (e.g. back, knee or hip) that could be made worse by a change in your physical activity?
7. Is your doctor currently prescribing drugs for your blood pressure or heart condition? YES/NO
8. Have you injured your hip, knee or ankle joint in the last six months? YES/NO
9. Do you know of any other reason why you should not participate in physical activity? YES/NO

Emergency: (please provide contact details of who you would like notified in case of an emergency)

Name: _____

Contact Number: _____

Thank you for taking your time to fill in this form. If you have answered 'yes' to any of the above questions, unfortunately you will not be able to participate in this study.

Please bring to completed form with you to the first habituation session. You will be given the opportunity to discuss your answers prior to the commencement of any tests. You will be asked to sign the form before each test session confirming that you are aware of the test protocols and you do not know of ant existing or previous medical condition that may preculde your participation in the study.

I (please print name) _____ have given true and complete information to the best of my knowledge. I confirm that I am not aware of any existing, or previous medical condition that may affect my ability to complete the test exercise sessions detailed in the "Participant Information Sheet" and that I have had the procedures fully explained to me and am fully aware of what is involved in the test protocols.

Athlete signature: _____ Date: _____

Appendix VII – ECB playing regulations (8 pages)