PHYSIOLOGICAL, PERCEPTUAL AND PERFORMANCE RESPONSES DURING CRICKET ACTIVITY

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ABSTRACT

The present study sought to determine the influence of environmental conditions and protective clothing on physiological, perceptual and performance responses during batting activity. The investigation examined mean skin temperature, average heart rate, estimated sweat rate, rating of perceived exertion, thermal sensation rating, average sprint time and pre-post choice reaction time.

Twenty-five cricketers (18-22 yr, 73.1 ± 9.6 kg, 1768 ± 75 mm, 12.6 ± 3.1% body fat, 1.89 ± 0.16 m^2) performed a work-bout consisting of a seven-Over batting period, during which time they faced deliveries from a bowling machine and performed two shuttle runs every third ball to total four sprints per Over. Trials were carried out under High-stress (23.8 ± 2.2 °C) and Low-stress (13.3 ± 1.9 °C) environmental conditions (WBGT). Within each environmental condition subjects performed the test wearing full protective batting gear and no protective gear. Thus, four specific conditions were examined; high full-gear (HFG), high no-gear (HNG), low full-gear (LFG) and low no-gear (LNG). Two-way ANOVAs were calculated to determine whether there were differences between environmental conditions and whether differences existed between the clothing conditions. One-way ANOVAs were utilised to compute differences between the four specific conditions combining clothing and environment.

High environmental stress and wearing protective clothing caused batsmen to experience significant physiological strain. The environment was the greatest stressor, with the protective gear exacerbating these effects. However, when padding

covered skin areas directly, this was the primary skin temperature stressor, particularly later in the activity. For skin temperature and heart rate, the strain was the most pronounced at the end of the trials.

Perceptual responses indicated that the protective gear had no influence on effort sense, thermal sensation or thermal comfort. However, environmental conditions had an effect, and High-stress conditions resulted in significantly higher perceptions of effort, elevated sensations of heat and greater thermal discomfort. Effort was perceived to be greatest towards the end of the trial.

There were mixed findings for performance factors. In general sprint performance was not hindered by environmental stress, but protective clothing caused a reduction in several sprint times. Choice reaction times were for the most part unaffected by either environment or clothing and few differences were observed between pre and post times.

It is contended that intense short duration batting activity, likely encountered during one-day participation, imposes a stress on batsmen. The stress is greater when conditions are warmer and protective padding is worn, although it is not sufficient to impede choice reaction time. However, protective gear did have a deleterious effect on sprint performance.

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CHAPTER I

INTRODUCTION

BACKGROUND TO THE STUDY

Intermittent activities such as batting in cricket have not been extensively studied (Burke and Hawley, 1997). At present the majority of research in cricket tends to focus on biomechanical analysis and primarily deals with bowling. Gore **et al**. (1993) and Burke and Hawley (1997) have identified the extreme conditions in which cricket can be played and the consequential potential thermal risk. Accordingly these same authors have identified a need to investigate thermal strain and the associated dehydration in cricket.

The game has evolved considerably since first being played in England some 400 years ago (Eagar, 1986). During the early stages the equipment used was crude and limited, the environmental conditions were generally mild and the nature of the game was slothful. Through the years cricket, like many other sports, has changed significantly. Development of the game has seen substantial changes in the nature of the activity plus the clothing worn, particularly the protective equipment now used. International interest has led to the growth of the game on several continents in both hemispheres. The environmental conditions in these areas are remarkably different to those pertaining in cricket's land of origin.

Over the years the most significant equipment developments have been the introduction and subsequent improvement of protective gear. In the early stages no protective gear beyond that provided by basic clothing was worn. Nowadays protective

gear is an essential component of the cricketer's armoury, in order to protect batsmen from contact injuries. Batsmen may have 80-90% of their body surface area covered by some form of synthetic protective wear or clothing. Unfortunately modern protective gear is designed primarily with protection from impact in mind, and according to Cheung **et al**. (2000), protective garments of this nature are for the most part not conducive to dissipating body heat.

The nature of the game has also seen dramatic changes from it being a fairly subdued form of recreation to a highly competitive international sport. Modern cricket matches typically take two forms, limited overs (1-day) and first class (4 to 5-day) matches. At the "elite" level, cricket is comprised of one-day international (ODI) matches and test matches, one-day matches being more intense (Noakes and Durandt, 2000) but of shorter duration, while the intensity of test matches are minimal (Fletcher, 1955) but the duration significantly increased.

At present International Cricket Council (ICC) membership is comprised of 10 Test-playing nations, with another 16 Associate and 31 Affiliate countries. The important factor regarding the expansion of the game is that vastly different climatic conditions are experienced in many of these relatively new playing spheres, particularly in respect of high ambient temperature and humidity. Both forms of the game are regularly played in climatic conditions that impose a high environmental heat stress on the participants.

It is imperative to investigate the effects of intense intermittent activity in extreme environmental conditions while wearing protective gear. Any form of activity produces heat as a result of energy metabolism. The human body is mechanically inefficient and

is only capable of using about a quarter of its energy for locomotion (Åstrand and Rodahl, 1977; Pyke and Sutton, 1992), with the remainder being given off as heat. High temperatures, high humidity and protective clothing all reduce the ability to lose the heat generated through physical activity. If the heat cannot be dissipated by the body, it will be stored and body temperature will rise. When this temperature rises more than 5 °C above normal, then the chance of developing heat-stress related disorders is greatly increased. Further increases in body temperature could even result in fatality.

The body's mechanisms of dry and evaporative heat loss are efficient when conditions are mild and activity is minimal, but problems arise when climatic conditions are extreme. Hot environments force the body to rely on evaporative heat transfer to a large extent, therefore sweat production is increased to facilitate insensible heat loss. However, high ambient temperatures in combination with high humidity decreases the evaporation efficiency, therefore the organism struggles to lose heat via this physical mechanism. Hot and humid conditions, coupled with high work intensities, place an individual in a compromised position, one that may result in rapid increases in core temperature. Such conditions also lead to large sweat losses and therefore potential hypohydration. Heat strain and hypohydration will intensify the longer these conditions are maintained.

Sports in which layered clothing ensembles and helmets are essential signify a potential risk for considerable heat storage, leading to thermal stress (Pascoe **et al**., 1994b). Cricket and other sports are dependent on protective wear. This equipment covers portions of the body and interferes with the natural heat transfer in these areas because the protective gear and uniform decrease the surface area exposed, add insulation and

limit vapour transfer from the skin to the environment (Holmér and Elnäs, 1981; Kenny **et al**., 1993). Cognisance needs to be taken of the factors that increase energy cost and therefore heat production as they may ultimately limit performance. These include the additional weight that must be carried (Fox **et al**., 1966) and decreased movement efficiency resulting from restrictive protective batting attire. Thus the limiting effect of batting gear on human thermoregulation and performance needs to be evaluated. The realisation of these effects is needed in order to improve equipment design.

Noakes and Durandt (2000) have suggested that the intensity of test matches is too low to induce hyperthermia. However, the extended duration of play could lead to substantial fluid losses that are not adequately restored, resulting in various levels of hypohydration. Since more metabolic heat is likely to be generated by players during ODIs, due to the higher intensity, this may also bring about significantly elevated body temperatures, particularly when batting gear hinders heat loss.

During cricket participation at the highest level, recovery intervals (namely the drinks, lunch and tea breaks) tend to remain unchanged, irrespective of the severity of the environmental conditions. It is therefore also necessary to evaluate recovery periods in order to establish appropriate work-rest intervals for diverse environments.

To obtain an in-depth understanding of an individual's responses to imposed equipment worn and environmental conditions, it is essential to take a holistic approach. According to Parsons (1993), humans respond to an environment by integrating physiological and psychological responses to the physical conditions. The importance of psycho-physical responses cannot be over-emphasised in an overall examination of reaction to a task.

Perceptual responses are determined by how individuals integrate information regarding the climate, their clothing and the activity. Individual perceptions of exertion, comfort and sensation all contribute to this overall appraisal. Since “man reacts to the world as he perceives it, and not as it really is” (Borg, 1970), his perceptions of this environment will influence his reactions and are likely to affect performance.

Thermal problems are widespread in sports such as running (ACSM, 1985; Noakes, 1996), team sports such as soccer (Elias **et al**., 1991) and more importantly, sports where protective gear is worn. Participants in these activities have suffered thermal injuries, and Spickard (1968), Knochel (1975) and Elias **et al**. (1991) report that American football has suffered numerous fatalities. From the period 1931-1975, 76 deaths in American football were attributed to heat stress and dehydration. The situation is not yet as demanding in cricket. However, the intense nature of the modern one-day game and the diverse, and more often than not, extremely hot environments experienced is of growing concern. Debilitating heat-induced problems aside, one of the major objectives of sports science is to enhance performance. There are many indications that physical (Terrados and Maughan, 1995), mental (Ramsey, 1995) and cognitive performance (Cian **et al**., 2001), both in sporting and occupational settings, are affected by thermally extreme conditions and hypohydration. Further information in this regard pertaining to cricket performance is needed.

This study aims to identify thermoregulatory and psycho-physical responses to batting activity and recovery thereafter by investigating these responses during favourable (Low-stress) and unfavourable (High-stress) environments whilst wearing different cricket ensembles.

STATEMENT OF THE PROBLEM

Modern cricket, particularly international cricket, demands that players perform at top level regardless of the playing conditions. There is a need to address the issues of thermal stress and clothing stressors in one-day batting. Wearing multiple protective layers in conjunction with hot and humid ambient conditions is likely to have a myriad of effects on batsmen, although the extent and impact of these stressors is unclear. A possibility exists that these stressors may ultimately impact the performance outcomes of one-day cricket. The purpose of this study was to investigate the influence that protective gear and extreme environments has over thermoregulatory measures, perceptual responses and standard of performance of cricketers.

RESEARCH HYPOTHESIS

The general hypothesis proposed was that thermoregulatory adjustments and perceptual responses during activity and recovery are significantly different under different clothing and environmental conditions. It was proposed that extreme thermal conditions induced by clothing and environment might be responsible for impaired performances.

STATISTICAL HYPOTHESES

HYPOTHESIS 1: ENVIRONMENT

1 (a) During simulated batting activity the physiological responses are no different between High environmental stress and Low environmental stress conditions.

Ho: $\mu_H = \mu_L$ (physiological)

Ha: $\mu_H \neq \mu_L$ (physiological)

1 (b) During simulated batting activity perceptual responses are no different between High environmental stress and Low environmental stress conditions.

Ho: $\mu_H = \mu_L$ (perceptual)

Ha: $\mu_H \neq \mu_L$ (perceptual)

1 (c) The performance responses of cricketers are no different between High environmental stress and Low environmental stress conditions.

Ho: $\mu_H = \mu_L$ (performance)

Ha: $\mu_H \neq \mu_L$ (performance)

Where: H = High environmental stress
L = Low environmental stress.

Environmental stress refers to the thermal stress imposed on individuals as a result of the combined interactions of ambient temperature, humidity, solar radiation and wind.

HYPOTHESIS 2: CLOTHING

2 (a) The second null hypothesis states that during simulated batting activity the physiological responses are no different between conditions where Full batting Gear is used and conditions where No batting Gear is used.

Ho: $\mu_{FG} = \mu_{NG}$ (physiological)

Ha: $\mu_{FG} \neq \mu_{NG}$ (physiological)

2 (b) During simulated batting activity the perceptual responses are no different between conditions in which Full batting Gear is used and conditions in which No batting Gear is used.

Ho: $\mu_{FG} = \mu_{NG}$ (perceptual)

Ha: $\mu_{FG} \neq \mu_{NG}$ (perceptual)

2 (c) The performance responses of cricketers are no different between conditions in which Full batting Gear is used and conditions in which No batting Gear is used.

Ho: $\mu_{FG} = \mu_{NG}$ (performance)

Ha: $\mu_{FG} \neq \mu_{NG}$ (performance)

Where: FG = Full batting Gear and clothing.
NG = No batting Gear (clothing only).

The responses as influenced by varied clothing and environmental stress conditions are assessed by means of body temperature, hydration, circulatory, perceptual and performance responses.

DELIMITATIONS

The sample was confined to 25 young adult male cricketers between the ages of 18-22 years. To ensure that subjects were of a reasonable calibre, the sample consisted of first league and provincial academy (Border and Eastern Province) players. Subjects included players specialising in all aspects of the game.

Players attended three testing sessions. At the initial session general demographic data were collected, an outline of the project explained and informed consent obtained. The following two sessions involved the testing of subjects during and after performing a simulated batting workload, under two separate environmental conditions. Within each of the High and Low environmental conditions the effects of two different clothing conditions were examined. These clothing trials involved the use of Full batting Gear or No batting Gear. Thermoregulatory, perceptual and performance data were collected at each of these sessions.

LIMITATIONS

1) The major limitation of this investigation was the control of environmental conditions. Batsmen participated in a field investigation in which two environmental conditions were examined. However, unlike laboratory-based studies, the ambient conditions within these trials varied considerably. In order to maximise variance between the two environmental conditions, testing occurred within different climatic seasons. Even though every effort was made to control these environmental conditions, by confining testing to periods when ambient conditions were appropriate, several test days still had to be cancelled. Thus the environmental conditions could not be tightly controlled and the data collection periods were significantly extended.
2) Since the environmental trials occurred at different stages of the playing season, the players' levels of physical condition may have differed. Several months separated these conditions and therefore training effects may influence physiological, perceptual and performance factors between trials. Training could significantly alter percent fat and body surface area (BSA) values.
3) If same day environmental variations were significant then it is possible that they would affect responses.
4) The work-bout was a simulated intermittent task. It may be questionable whether this task can be generalised to cricket activity, which is more random and unpredictable in nature.
5) The work-bout was based on observations of one-day international matches, an intensity which is much greater than that of test matches. Therefore the results are not likely to be generalised to longer forms of the game.

6) Within each environmental condition both clothing conditions were assessed on the same day. There may have been a fatigue effect in the second trial of the day; however, trials were randomised to offset this effect.

CHAPTER II

REVIEW OF RELATED LITERATURE

INTRODUCTION

It is generally accepted that six basic parameters govern the human thermal environment: ambient temperature, humidity, solar radiation, wind, clothing and energy expenditure (Parsons, 2000). Interactions of these elements determine the thermal stress imposed and the strain experienced by individuals in various industrial, athletic and daily living situations. Participation in sporting activities occurs in various environmental conditions, resulting in diverse situations often of extreme environmental stress.

Burke and Hawley (1997) have noted that many sports involving vigorous activity also require participants to wear protective gear. Cricket is no exception in this regard particularly in the case of batsmen who must use protective wear despite extreme environmental conditions. Numerous sporting activities become problematic in hot and humid conditions (Pyke and Sutton, 1992). Heat related problems in these environments are worsened when clothing or gear is worn which has high insulative properties and in which the intensity of activity is high (Nunnely, 1988; Meir **et al**., 1994). Batsmen spending extended periods in extreme conditions are likely to experience some degree of heat strain and discomfort. Clothing and climate will probably influence how an individual perceives the effort required for a particular activity and also perception of thermal discomfort (Brownlie **et al**., 1987; Parsons, 1993).

Under these conditions one observes an increased heat load and sweat loss, which may become dangerous because of the possibility of developing hyperthermia and/or dehydration, both of which may eventually limit physical (Armstrong **et al**., 1985; Walsh **et al**., 1994; Below **et al**., 1995; Latzka and Montain, 1999) and mental (Hancock, 1981; Gopinathan **et al**., 1988; Ramsey, 1995) performance and increase the risk of developing some form of heat disorder.

Currently there is little awareness of how protective gear influences fluid loss and temperature regulation in batsmen, and there are few specific guidelines to follow regarding appropriate fluid intake. There has been limited research investigating cricketers' perceptions of the batting activity under conditions of Low thermal stress, let alone in environments of High thermal stress. Performance changes and the relation to physiological and perceptual responses to various playing situations are poorly understood, thus this study investigated the effect that clothing and environment have on physiological responses, perceptual responses and performance. This was achieved by observing cricketers during and after a simulated batting specific work-bout.

NATURE OF THE GAME

At a world class level, cricket typically takes two forms, one-day international (ODI) and five-day (test) matches. Test matches involve six hours of play per day and each day has three (two-hour) sessions of play. The intervals between each session are lunch and tea, which are 45 and 20 minutes respectively. Each two-hour session is divided by a five-minute drinks interval. Also of interest is the 10-minute interval at the change of innings. One-day internationals involve two 3.5-hour sessions per game, and the lunch or supper interval between is 40 minutes. Two drinks breaks per session are permitted,

each 1 hour 10 minutes apart, although under conditions of “extreme heat”, the umpires may permit extra intervals for drinks (ICC, 1998). Tests are always played in the day, but ODIs may be played during the day or at night under floodlights.

A simple means of classifying cricket matches is in terms of intensity and duration. Test matches are clearly of much greater duration; both batting and bowling activities in these matches are carried out at a relatively low intensity (Fletcher, 1955). On the other hand, all facets of the one-day game, namely fielding, batting and bowling, are far more intense, although the duration is considerably less. This study is primarily concerned with batting and is based on the work rate of one-day international matches. It is apparent from estimations of batting in one-day matches (Noakes and Durandt, 2000) that the demands are substantial.

CHARACTERISTICS OF CRICKET PLAY

In both forms of the game cricketers are required to spend extended periods on the field of play, specifically whilst fielding. The total duration is increased if batsmen also spend a substantial period at the “crease” batting. During test matches participants regularly spend a day or more fielding, and sometimes players can field for up to twelve hours over two consecutive days. Once a team has finished fielding, they must return to bat. In these situations opening batters are likely to return to the field considerably fatigued and having had little time to rehydrate or replenish fuel stores. These batters are expected to bat for extended periods wearing layers of protective gear. It must therefore be acknowledged that players may well experience fatigue and exhaustion. In ODIs a similar scenario is possible although the amount of time spent fielding and batting is greatly reduced by comparison to a test match. The foremost difference is the intensity

at which the ODIs are played and the greater stress (physical and psychological) experienced by players.

ENVIRONMENTAL FACTORS

Of the six basic factors influencing human thermal environments, four are environmental determinants. Shephard (1988) and Parsons (1993) note that air temperature, radiant temperature, wind velocity and humidity are the four basic environmental parameters that should be quantified when considering human thermal environments. These four factors determine the level of heat stress imposed by the environment (Pyke and Sutton, 1992).

Air temperature (T_A), also known as ambient or dry-bulb temperature, is commonly measured with a mercury (dry-bulb) thermometer. Heat energy is exchanged by radiation between all bodies, and the net flow of radiant heat between the human body and the environment is dependent on the surface temperature of the body and the average temperature in the environment. A suitable means to summarise radiant heat exchange between the body and environment is the mean radiant temperature, which provides an overall average value of radiant temperature. A common method used to measure the radiant temperature is the black globe temperature (T_G).

The humidity of the air can be expressed in a number of ways; commonly used measures are relative humidity (RH), partial vapour pressure (P_a) and dew point temperature. The relevance of humidity to human thermal interaction with the environment is its influence on the water vapour gradient between the skin's surface and the environment. The higher the humidity, the smaller the water vapour gradient

between the moisture (usually sweat) on the skin's surface and the environment, thus sweat is slow to evaporate.

Air movement across the body influences heat exchange to and from the body and as such the body temperature. The air movement may enhance cooling by increasing the evaporation and removing the layer of warm air molecules surrounding the individual, therefore increasing the convective cooling process. However, this combination of air movement can lead to increased heat load if the air removed is replaced by warmer air than itself. The higher the velocity of the wind, the greater is the cooling efficiency.

ENVIRONMENTAL STRESS INDICES

When observing the heat stress imposed on an individual, it is commonly understood that this stress is representative of the interaction of environmental factors (previously mentioned), metabolism (energy production) and clothing. Therefore the strain experienced by humans is related to the interactional effect of these elements. Lee (1980) points out that the search for a standard that can be utilised to reduce or eliminate heat stress has gone on for nearly a century. Numerous standards for various conditions and settings have been developed and combinations of these standards have been implemented to provide indices. These indices provide an overall expression, which integrates the various factors contributing to heat stress. These indices are numerous and the endeavour of many authors to provide a single universal index will always be fraught with difficulties. Indices have been derived via several approaches namely empirical, direct and rational indices (Parsons, 2000). Goldman (1988) suggests that a single universal index is unworkable.

Environmental stress alone can be evaluated in terms of direct (physical) indices that generally account for one or more physical factors (i.e. air temperature, radiant temperature, wind speed and humidity). Physical indices are designed to assess environmental demands and predict the heat load on the individual. Naturally one would desire an index that is likely to incorporate more factors, particularly if the index is to be applied in a variety of climatic situations. One such method is the Wet Bulb Globe Temperature (WBGT) index, which is one of the most commonly used outdoor methods (Pascoe **et al**., 1994a; Fox, 1979; Rodahl, 1989), and incorporates the four basic environmental parameters.

Wet Bulb Globe Temperature Index

Yaglou and Minard originally developed the WBGT index in 1957. The WBGT index combines the effects of several temperatures: a) ordinary air temperature (T_A), measured with a dry-bulb thermometer, b) temperature as affected by wind and humidity, the convective-evaporative wet bulb cooling, measured with a naturally ventilated wet-bulb thermometer (T_{NW}), and c) temperature as affected by radiant heat from the sun. Radiant heat absorption is measured with a black globe thermometer (T_G). This index involves a simple weighting of temperatures and is calculated as follows:

$$WBGT\ (°C) = 0.7 \times T_{NW} + 0.2 \times T_G + 0.1 \times T_A$$

The WBGT index is probably the most universally used method; it has been used extensively, for both practical and research purposes, as an indicator of environmental heat stress and as a means to prevent thermal injuries in numerous fields: a) athletics and sport science, running (ACSM, 1996; McCann and Adams, 1996), cricket (Gore **et**

al., 1993), general athletics (Noakes, 1992), football (Tsujita **et al**., 1998); b) the military (Yaglou and Minard, 1957; Epstein **et al**., 1999); and c) occupationally (OSHA, 1974; NIOSH, 1986; ISO 7243, 1995; Becque and Linn, 1998). The simplicity of the index and its use by influential bodies has led to its widespread acceptance. Haymes and Wells (1986) and Rodahl (1989) consider the WBGT index to be an acceptable method of describing the total environmental stress imposed on man, and according to Parsons (1995), provides a simple convenient means of evaluating hot environments.

The WBGT, like all direct indices, has limitations when used to simulate human response. The use of WBGT as a universal tool for indicating heat stress and predicting possible strain may, in certain circumstances, be problematic. Kerslake (1982) believes that even though WBGT is excellent for the specific role for which it was constructed, the index was not intended for standard use in other contexts. Moran and Pandolf (1999) consider the index to be limited because of its lack of applicability to situations where individuals are wearing different types of clothing, such as protective gear, as well as the need for corrections and adjustments to WBGT to account for differing work rates and clothing conditions.

Even though there is apprehension regarding the general applicability of WBGT index to situations other than those for which it was designed, there is still merit in this method. The WBGT index is not necessarily the best predictor of human responses to thermal stress (i.e. thermal strain) in all situations, but is still a good indicator of environmental conditions, since it provides an overall estimation of environmental stress by incorporating the four physical factors, while other methods are less comprehensive in this regard.

Appropriate Indices for Cricket

The ACSM (1985) states that the WBGT provides the most useful index of potential heat stress and has used the index to formulate guidelines for preventing heat disorders. The cautions listed below (Table I) form the basis of the ACSM's guidelines for the prevention of thermal injuries for distance runners. However, it is felt (Fox and Mathews, 1981) that these precautions may only be applicable to sporting activities in which heavy protective clothing is not a problem i.e. soccer, field hockey, tennis, athletics and general training. Naturally the standard attire of cricket batsmen will influence the applicability of the ACSM running guidelines, which may not be appropriate for preventing thermal disorders in batsmen.

TABLE I: **ACSM (1985) guidelines for prevention of thermal injuries in distance running.**

WBGT	**RISK**
<10°C	Hypothermia Risk
10-18°C	Low
18-23°C	Moderate
23-28°C	High
>28°C	Extreme

A more relevant method may be the Football Weather Guide (Table II), which was constructed from data on heat stroke disorders and fatalities in American football (Fox and Mathews, 1981). It provides guidelines that may be more applicable to sports where protective gear is worn.

TABLE II: The football weather guide (Fox and Mathews, 1981).

Air Temperature		Danger Zone	Critical Zone
°F	°C	% RH	% RH
70	21.1	80	100
75	23.8	70	100
80	26.6	50	80
85	29.4	40	68
90	32.2	30	55
95	35.0	20	40
100	37.7	10	30

Haymes and Wells (1986) have also suggested using Occupational Safety and Health Association (OSHA) WBGT guidelines to prevent heat disorders in sport (Table III). Even though the OSHA WBGT recommendations may not be strictly applicable to sporting situations such as cricket, they do give an indication of working threshold environmental levels and also make allowance for various work rates and differences in wind speed.

TABLE III: **Recommendations of OSHA committee for heat stress threshold values for WBGT (from Haymes and Wells, 1986).**

WORK LOAD	Low Air Velocity $<1.53\ m.s^{-1}$	High Air Velocity $>1.53 m.s^{-1}$
Light $<837\ kJ.h^{-1}$ (200 $kcal.h^{-1}$)	30.0	32.2
Moderate 841-1256 $kJ.h^{-1}$ (201-300 $kcal.h^{-1}$)	27.8	30.6
Heavy $>1256\ kJ.h^{-1}$ (300 kcal. h^{-1})	26.1	28.9

Another similar method of heat stress evaluation is to compare WBGT with the NIOSH recommended heat stress alert (RAL) and ceiling limits. Figure 1 is a graphic

representation of the incorporation of the NIOSH method and ACSM's running guidelines.

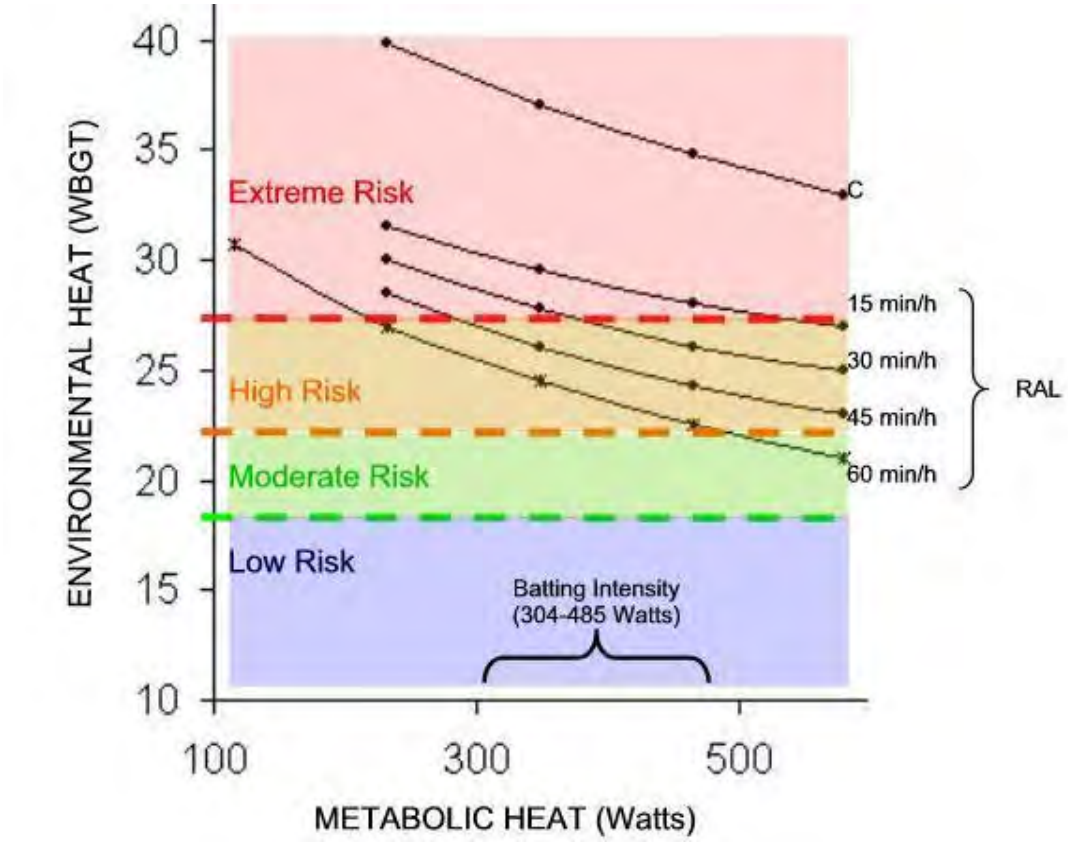


FIGURE 1: **Graph incorporating NIOSH and ACSM guidelines.**

An estimate of the metabolic heat generated while batting is between 304 and 485 Watts (1094 and 1748 $kJ.h^{-1}$), thus, placing batting activity at the higher end of the scale (as shown in Figure 1). This range of energy expenditure is calculated from batting (test matches and net situations) intensity estimations (Fletcher, 1955). Christie **et al**. (In Press) measured the metabolic cost of a simulated one-day batting activity as 704 Watts (2536 $kJ.h^{-1}$), although it is unlikely that this level of activity would be sustained for an entire session of play. The energy expenditure will vary considerably depending on situations of play itself.

The longest uninterrupted period that an international player is able to bat for is 1 hour 10 minutes in an ODI match and about an hour in a test match. Combining the estimated energy expenditure (test matches) and typical duration that a player must bat, it would appear that their recommended heat stress alert (RAL), according to NIOSH, should be in the region of 23-25 °C (WBGT). According to OSHA (Table III) the threshold WBGT levels for work of this moderate-high intensity would range between 26-30 °C depending on wind speed. However, according to the ACSM (1985) running guidelines, which make no distinction between running intensity, the RAL and threshold environmental conditions recommended by NIOSH and OSHA respectively range from the high-risk category and beyond. Both Noakes and Durant (2000), and Christie **et al**. (In Press) proposed that the demands of ODI cricket are greater than Fletcher's estimations. In addition, limited over and test cricket is often played in conditions above these critical levels (see Table IV), yet despite this, very few heat disorders have been documented. Thus the use of these guidelines is questionable in cricket arenas and highlights the need for guidelines that are specific to cricket.

Climatic Conditions of Cricket Regions

Estimations of environmental heat stress (WBGT) for various cricketing regions are represented in Table IV. The estimates have been made from average climatic data. King and Christie (2001) examined climatic data from the numerous cricket-playing regions and selected one or two areas from each of the test-playing nations. The regions selected represented the highest environmental heat stress exhibited in a particular country. The heat stress was determined from the monthly average of daily maximum temperature, and monthly average of afternoon RH. The humidity values were converted to T_{NW} so that WBGT could be estimated from calculations of the

modified discomfort index (Moran **et al**., 1998; Moran and Pandolf, 1999). Table IV illustrates the highest and average daily temperature, the mean afternoon RH, the estimated WBGT and corresponding environmental stress category (ACSM, 1985) for a particular month. According to these figures a region in every test nation has at least one period (month) of high or very high environmental heat stress, with the exception of England, where the game originated and initially developed. Only the most stressful months from each region are identified below, but there are many areas where the typical thermal stress is estimated at greater than 23 °C (WBGT).

TABLE IV: **Heat stress of cricket playing regions (reported by King and Christie, 2001).**

Country (City)	**Temperature for particular month (C°)**		**Ave Monthly Afternoon Relative Humidity (%)**	Estimated WBGT Index	
	Highest Temp	**Ave Daily Max Temp**		**Value**	**ACSM Environmental Stress Category**
Australia (Brisbane)	41	29	60	**28.0**	**High**
England (London)	34	21	62	**20.5**	**Intermediate**
India (Mumbai)	36	32	71	**32.2**	**Very High**
India (Madras)	39	34	70	**34.1**	**Very High**
New Zealand (Napier)	34	24	60	**23.2**	**High**
Pakistan (Peshawar)	43	36	39	**31.2**	**Very High**
Pakistan (Karachi)	44	32	62	**31.1**	**Very High**
South Africa (Durban)	34	28	69	**27.2**	**High**
Sri Lanka (Colombo)	33	31	70	**31.2**	**Very High**
West Indies (Trinidad)	36	32	74	**32.6**	**Very High**
Zimbabwe (Harare)	30	26	52	**24.0**	**High**

It is concluded that although the WBGT is a good measure of the overall environmental load (stress), it is not considered to be the best measure of the overall thermal stress, which may be a result of environmental, clothing and metabolic factors. The limits set for determining the strain experienced are likely to be relevant to a particular situation. For cricketers appropriate guidelines for predicting the possibility of developing heat

disorders remain undecided. However, for the purpose of batting activity in cricket or other outdoor sports involving substantial protective gear, the Football weather guide may be the most suitable means to identify the level at which heat strain becomes a problem.

HUMAN THERMOREGULATION

BODY TEMPERATURE REGULATION AND HEAT BALANCE

For humans to function effectively the core temperature needs to be maintained within a narrow range. Maintenance of a relatively stable core is crucial as temperature extremes will damage tissues or possibly cause tissue necrosis. Deep body temperature is typically in a state of dynamic equilibrium at 37 °C with a diurnal variation between 0.3 and 1.5 °C (Åstrand and Rodahl, 1977; Kerslake, 1982). Normal core temperature fluctuates only about 5 °C (35 to 40 °C). However, Pascoe **et al**. (1994a) point out that under extreme conditions the body is able to balance temperatures within the limited (25 to 45 °C) "range of survival", but the core can only tolerate internal temperatures outside its normal range for short periods.

Humans are considered to be regulating organisms capable of maintaining body temperatures within the survival range even under widely divergent conditions. It is generally accepted (McArdle **et al**., 1991) that body temperature, specifically core temperature, is in a state of dynamic equilibrium. This state of thermal balance is achieved when factors of heat loss and heat gain are in equilibrium. Naturally if the mechanisms of heat gain exceed the mechanisms of heat loss then the body stores heat and the heat content will increase. Similarly if heat loss surpasses heat gain, body heat content diminishes. The body gains heat directly from the reactions of energy

metabolism as well as absorbing heat from the environment (McArdle **et al**., 1991). Heat is dissipated via the physical mechanisms of radiation, convection conduction and evaporation (McCormick and Saunders, 1982).

Depending on the environmental and situational conditions, certain physical mechanisms may either contribute to, or subtract from, the body's thermal load. The Law of Conservation of Energy best describes the process and states that for a system to be in thermal balance all avenues of heat gain or loss must quantitatively balance zero. This can be expressed by the following formula:

$$M \pm R \pm K \pm C - E \pm W \pm S = 0 \text{ (thermal balance)}$$

Where:

Rate of heat production refers to the difference between the total rate of *metabolic energy production (M)* and *(W)* the rate at which *external work* is being performed (Kerslake, 1982). M is the total energy released by all anaerobic and aerobic processes.

Radiation (R) is the exchange of electromagnetic waves emitted from one object and absorbed by another.

Conduction (K) is the direct transfer of heat that occurs between two surfaces of differing temperatures that are in direct contact.

Convection (C) is the physical exchange of heat between the body and an adjacent moving medium.

Evaporation (E) is the transfer of heat to the environment through vaporisation of water.

Humans are able to effectively regulate the core temperature through behavioural and physiological changes, the autonomic system being primarily in control of physiological adaptations. Behavioural changes are the most effective means of combating any thermally challenging environment (Pyke and Sutton, 1992; Parsons, 1993).

Behavioural changes include actions such as moving from a less favourable to a more favourable environment or modifying one's clothing. Unfortunately, in sporting situations such as cricket, players are often required to participate in sub-optimal clothing and environmental conditions without opportunity to bring about a satisfactory behavioural change. Under circumstances such as this, maintenance of thermal balance is largely reliant on the body's own physiological mechanisms of heat regulation and there are limitations to these processes.

HYPOTHALAMIC TEMPERATURE CONTROL

The hypothalamus controls many bodily activities and is one of the major regulators of homeostasis in the body (Tortora and Grabowski, 1993). Along with the other physiological processes temperature regulation is under the control of the hypothalamus (Åstrand and Rodahl, 1977). Although other brain regions also contribute to thermoregulation (Marieb, 1992), the hypothalamus is the major integrating and co-ordinating centre for the various processes of temperature regulation (McArdle **et al**., 1991). According to Haymes and Wells (1986), this area acts as a thermal sensor, integrates information from other locations and controls various effector mechanisms, which either increase or decrease the body's ability to conserve or dissipate heat. A model proposed by Haymes and Wells (1986) suggests that sensory input is received from skin receptors, central receptors, deep peripheral receptors and the thermoceptive area of the hypothalamus.

The temperature regulatory centre is, in effect, an in-built biological thermostat (Kerslake, 1982). If the assimilated sensory information reveals that the body temperature is above the set point then the hypothalamus signals heat dissipating

mechanisms. This initiates peripheral vasodilation and sweat production. Cold receptors may indicate that the body is below the set point, in which case neural discharge from the hypothalamus is increased and the mechanisms that conserve heat vasoconstriction and shivering are initiated (Haymes and Wells, 1986).

HEAT DISSIPATING MECHANISMS AND THEIR INTERACTION

Once the central regulatory centre has identified conditions in which heat must be dissipated, the heat dissipating mechanisms are set in motion and it is an integration of these heat-dissipating mechanisms that optimises heat loss. McArdle **et al**. (1991) indicate that the mechanisms of heat loss are identical, whether the heat load is imposed internally (metabolic heat) or externally (environmental heat). Physiological mechanisms include circulatory adjustments, increased sweat production and hormonal adjustments.

An important function of the circulatory system is to provide fine-tuning for temperature regulation by transporting heat either to facilitate cooling or to optimise heat retention (McArdle **et al**., 1991; Sutton, 1996). A rise in the body's core temperature due to metabolic heat production, environmental temperature or a combination of both, will activate heat-dissipating mechanisms. Peripheral vessels dilate and warm blood is channelled to the cooler periphery (Leski, 1994). This results in a rise in the skin temperature, which greatly increases thermal conductance (McArdle **et al**., 1991; Åstrand and Rodahl, 1977), and therefore the amount of heat given off per square metre of body surface area per hour. This process favours radiative and conductive heat loss to the environment especially from the hands, forehead, forearm, ears and

tibial areas. Naturally if these sites are covered, as with protective batting gear, heat transfer will be reduced in these areas.

The body increases sweat production in order to facilitate heat dissipation. When evaporation of water or sweat on the skin's surface occurs it cools the skin. Thus blood directed from the core to the surface is cooled. Evaporation of sweat is the body's primary means of dissipating heat (Brukner and Kahn, 1993; Burke and Hawley, 1997); this is especially true in hot environments. The vaporisation of water from the skin's surface or respiratory passages transfers heat to the environment. For each litre of water evaporated, 2427 kJ (580 kcal) of energy are extracted from the body and conveyed to the environment (Shephard, 1988).

The concurrent stimulation of sweat glands, evaporation of moisture on skin and large cutaneous blood flow makes for an efficient cooling mechanism. Effectively these processes increase the temperature gradient between the cutaneous blood vessels and skin, thus allowing enhanced heat flow. Heat loss from the skin to the environment is increased so blood is cooled before being returned to the core (Haymes and Wells, 1986; Parsons, 1993). With an increase of sweat production and subsequent fluid loss, hormonal adjustments of the system initiate conservation of salts and fluids (McArdle **et al**., 1991; Latzka and Montain, 1999).

PHYSICAL EXERTION IN HEAT AND HUMIDITY

> **"**To perform strenuous exercise under climatic conditions that prevent the almost immediate loss of body heat or that add an external heat load immensely compounds the physiological problems" (Haymes and Wells, 1986, pp 22).

The body primarily gains heat from two sources, energy metabolism and the environment. Under "thermo-neutral" resting conditions these gains are adequately regulated because, as McArdle **et al**. (1991) maintain, the body's thermoregulatory mechanisms are primarily geared towards heat dissipation. Noakes (1992) contends that the major physiological problem faced by an athlete during exertion is that of losing excess heat produced by muscular contraction, and when ambient temperatures are high, dissipation of body heat becomes more difficult. Thus the physiological problems associated with physical activity are magnified when in hot environmental conditions.

In addition to thermoregulatory difficulties in hot environments, sustained exertion, especially in a hot and humid environment, can lead to exertional heat illness (Gardner **et al**., 1996) and has been identified as a problem in the sporting codes of distance running (ACSM, 1985; Roberts, 1992; Noakes, 1996), American football (Mathews **et al**., 1969) and soccer (Elias **et al**., 1991), and also military operations and training (Dreyfuss, 1991; Gardner **et al**., 1996).

Heat Generation

With an increase in muscular activity there is an increase in oxygen consumption and energy production. The process of converting chemical energy stored in ATP into mechanical energy is extremely inefficient (Noakes, 1992). Humans are approximately 25% mechanically efficient during work, the remaining 75% of energy being released as heat (Åstrand and Rodahl, 1977). Skeletal muscle contraction during exertion is responsible for 90% or more of the body's thermal load (Pascoe **et al**., 1994a), while at rest muscle only produces 18%, the remainder being produced by metabolically active liver, kidney, brain and heart (Brenglemann, 1989). Hence larger individuals tend to

have more metabolically active tissue than smaller persons, which suggests a higher basal metabolic rate and larger energy production for similar tasks. Consequently larger individuals need to dissipate more heat when active at the same absolute intensity as smaller individuals. Also heat production increases with energy expenditure, that is to say more vigorous activities will generate more heat and therefore more heat will need to be dissipated.

Random intermittent activities such as batting can also generate substantial metabolic heat. Batting in one-day matches often requires short bursts of all-out activity and during batting the sprint bouts are typically less than six seconds. Noakes and Durandt (2000), and Stretch **et al**. (2000) identified that maximal work of this duration is dependent on phospagens (ATP and PCr) and oxygen independent glycolysis to supply fuel for high intensity muscular contraction.

Heat Dissipation

To understand the manner in which body heat is dissipated in hot and humid environments, one must recognise the way in which heat is transferred via radiation, conduction, convection and evaporation, and the basis for disruption of these physical mechanisms.

Radiant heat exchange occurs between any two bodies in the universe that have a difference in temperature (Clark and Edholm, 1985). This energy is in the form of electromagnetic radiation and no direct contact of objects is required for the transfer of heat energy to occur. The net exchange of radiant heat between the environment and body is dependent on the temperature difference between these two systems. If the

body is hotter than the environment it will lose heat to the environment. The converse is also true. The major source of radiant heat absorbed by the body is from direct or reflected sunlight. Clothing worn and the amount of direct sunlight have implications for radiant heat exchange. Clothing covers the skin, effectively decreasing the surface area exposed to radiant heat exchange. This barrier may hinder heat loss, by trapping an insulative layer of air around the body, but may also shield the body from radiation. Radiant heat is influenced by the colour and texture of the surface exposed (skin or clothing). Clark and Edholm (1985) reveal that no matter what the colour of skin, it absorbs 97% of infrared radiation, while white skin and black skin reflect about 35% and 16% respectively of visible light radiated from the sun, although over the whole light spectrum 60% and 80% respectively of incident radiation is absorbed. The greater the amount of radiation absorbed the greater the heat energy stored. Not all of the body's surface area is open to the environment for radiant heat exchange as some areas radiate to adjacent skin areas. It is generally assumed that 70 to 85% of the surface area is open for effective radiation to the environment (Pascoe **et al**., 1994a), however clothing may cover large portions of this surface area. In cricket the batsmen have a large surface area covered by clothing and protective gear. These coverings create a barrier to environmental radiation that protects the cricketer. The clothing may afford protection from radiation (Shephard, 1988; Moran, 2001) but Cheung **et al**. (2000) argue that it is likely to interfere with the evaporative and other processes of dry heat loss.

Conductive heat exchange requires the direct contact of solid, liquid or gas molecules for energy to be transferred. In the body, heat may be conducted from the deep tissues to the surface tissues, or the opposite direction. The direction of convective heat energy

flow is dependent on the direction of the temperature gradient between these areas. At the surface, heat exchange occurs by direct contact with the air or other media. According to Pascoe **et al**. (1994a), conductive heat flow is dependent upon the specific heat of substances, the relative mass of the two bodies and the thermal resistance between contacting surfaces, thickness of the conductor, temperature differences between surfaces and the area of contacting surfaces. This can be used to explain conductive heat flow between the core and the peripheral skin, skin and surface air boundary, skin and clothing, clothing and environment, and skin and environment. Naturally conduction is influenced by clothing and protective gear as these create an obstruction that restricts heat flow. The thermal resistance particularly of the protective gear, largely due to the insulation properties of clothing and trapped air, is high and will restrict conductive heat exchange in these areas. Thus, clothing and specifically protective gear limit conductive processes.

A fluid such as water or air usually surrounds the body, and *convection* refers to the heat exchange between the body surface and this fluid (Santee and Gonzalez, 1988). This movement or convection is responsible for heat loss. Convective heat flow at the skin's surface is dependent upon the surface area exposed to convective currents, convective environmental characteristics and the difference between skin temperature and the medium (Pascoe **et al**., 1994a). Air adjacent to the skin or clothing is warmed and begins to rise because of increased buoyancy, a process termed free convection. This air forms a natural boundary layer and if air is relatively static, the air will act as a layer that insulates the body. Body movements and wind, termed forced convection, displace the natural convective boundary layer and increase convective heat transfer (Clark and Edholm, 1985); as a result free convection processes are more important in

still or slow moving air (Santee and Gonzalez, 1988; Pascoe **et al**., 1994a). Convective heat loss is influenced largely by the rate of movement of air or other fluid in contact with the skin because the air surrounding the body, which has been warmed, is continually replaced by cooler air, provided that the air temperature is below skin temperature. Thus on hot days, cooling of the body is significantly assisted by a strong wind as long as the skin is exposed to these air currents. Cricket clothing covers the body and prevents easy access of air currents to the skin's surface, although limited air movement does occur under the garment. Additionally, protective gear is largely impenetrable to air movement through the material and tends to trap air beneath it, which will insulate the body. These characteristics of clothing and protective ensembles essentially limit the cooling benefits obtained by strong wind.

When the ambient temperature is greater than the skin temperature, the body will gain heat from the environment through the mechanisms of radiation, conduction and convection. If the environmental conditions are severe enough, the normal temperature gradient between the surface and the core is reversed, and therefore body temperature is unable to be conducted to the surface to be released to the environment (Haymes and Wells, 1986). In such a situation the body relies exclusively on the *evaporation* of sweat and moisture for removal of excess body heat. The sweat rate increases as ambient temperature (McArdle **et al**., 1991) and energy expenditure increase (Noakes, 1992), which will aid evaporative cooling in hot conditions.

Sweat is clearly the body's most effective cooling mechanism when the air temperature approaches that of the skin (≈33 °C). However, if the sweat does not evaporate it will not cool the skin. In high humidity sweat forms on the skin's surface but does not

evaporate (Sutton, 1996); sweating in such conditions as indicated by McArdle **et al**. (1991) represents a useless water loss that can lead to a dangerous state of hypohydration and overheating.

Pascoe **et al**. (1994a) state that the total amount of sweat evaporated from the skin depends on three factors; 1) amount of wetted skin exposed to the environment, 2) the vapour pressure gradient and, 3) forced or natural convective air currents about the body. Clothing or the protective gear worn by the individuals can also influence all of these factors. In cricket the clothing or gear worn is largely controlled by the activity being performed (i.e. batting or bowling). By far the most important factor that determines the effectiveness of evaporative heat loss is the relative humidity (Sutton, 1984). When humidity is high the ambient vapour pressure approaches that of moist skin, and as the vapour pressure gradient decreases, less evaporative cooling is possible (McArdle **et al**., 1991; Pascoe **et al**., 1994a), essentially closing this avenue of heat loss. As long as humidity is low, relatively high environmental temperatures can be tolerated (McArdle **et al**., 1991; Leski, 1994). However, cricket is often played in regions where the humidity and ambient temperatures are high. With limitations to the heat loss mechanisms, the conditions that are commonly experienced in many cricket playing regions may create a significant thermal challenge to batsmen performing at a high work rate (1-day matches) or if batting for extended periods (4 to 5-day matches). Extended play in hot and humid environments may also result in prolonged sweating, which if unchecked is likely to produce significant levels of hypohydration. The clothing and protective gear worn by batsmen will further limit the already compromised avenues of heat loss as well as exacerbate dehydration.

Considering the effect of clothing, Pascoe **et al**. (1994a) observe that clothing permeability and surface area exposed would influence evaporation. If this barrier is vapour impermeable then any moisture that evaporates from the skin's surface becomes trapped. This increases the saturation of the air layer next to the skin and creates a humid microclimate around the skin thus hindering evaporation (Pyke and Sutton, 1992; Pascoe **et al**., 1994a), which promotes a rise in skin temperature and sweating. Convective air currents will also facilitate the evaporation process, but clothing and protective gear may limit this process by not enabling the free movement of air through or underneath the garment. Protective gear in particular is not permeable to air and allows very little, if any, movement of air under the gear, thus those areas covered by protective gear such as the shins, knees, areas of the thigh, hands, chest, forearm and a significant portion of the head have limited evaporative potential.

Pyke and Sutton (1992) identified certain characteristics of the individual as being related to the various physical processes of dry and evaporative heat loss, namely body surface-mass ratio and body composition. Body surface area (BSA) is notable since heat transfer is considered to be proportional to area exposed (Parsons, 1993). Furthermore, Pascoe **et al**. (1994a) identified that the extremities play an important role in thermoregulation as the skin in these areas contributes to over 65% of the total surface area of the body, while Holland **et al**. (2002) note the head accounts for 7 to 10% of the total BSA. However, in batsmen the lower extremities are totally covered by clothing and partially by protective gear, while the upper extremities are partially covered by both clothing and protective wear and a large portion of the head lies beneath the helmet. The apical regions have a high surface-to-volume ratio thus

increasing heat transfer capabilities; however, while batting the feet and hands are covered by shoes and leather gloves.

Circulatory Adjustments to Exercise and Thermal Stress

Haymes and Wells (1986) claim that cardiovascular efficiency is the key to determining one's ability to tolerate strenuous exercise in the heat, more so than any other single physiological factor. The circulatory system serves as a major transport system for the components of metabolism as it carries oxygen, glucose and metabolic substrates to metabolically active tissue and also removes the waste products of metabolism (carbon dioxide, lactic acid, ammonia).

There are competing demands of circulation when exercising in warm or hot environments. During conditions of exercise-heat stress, such as batting, the body must simultaneously provide sufficient blood flow for working muscles and adequate skin blood flow for thermoregulation (Sawka and Wenger, 1988; Sutton, 1996). Dual demands of the circulatory system are met comfortably unless the conditions are extreme. When environmental temperatures are high, the core-to-skin gradient is reduced so that the skin blood flow needs to be relatively high to achieve heat transfer sufficient for thermal balance (Sawka and Wenger, 1988). A rise in skin temperature, from environmental load or excess padding, is likely to result in increased dilation of peripheral veins (Sawka and Wenger, 1988), which increases skin blood flow (Nadel **et al**., 1979). This causes blood to fill these veins and enlarges peripheral venous volume (Rowel, 1974) thereby lowering central circulatory volume (Nadel, 1979; Noakes, 2001). Those areas that are covered by batting gear, particularly the legs and forearm, will probably demonstrate increases in skin temperature, which is likely to induce pooling of

blood. Unless counteracted for, this will result in a drop in venous return, and reduce cardiac filling. Rowel **et al**. (1965) state that in the heat, sufficient blood flow to the working muscles and periphery is realised by sacrifices to tissues that are able to temporarily compromise their blood flow supply. Compensatory responses of the body include reductions in splanchnic (Rowel **et al**., 1965) and renal blood flow (Smith **et al**., 1952) and increases in heart rate (Roberts and Wenger, 1979). These adaptations compensate for decreased stroke volume and assist in preventing a drop in cardiac output. Ultimately this may have a negative impact on cardiovascular efficiency, although this does not necessarily imply that there will be a reduction in any aspect of cricket performance.

When there are conditions of considerable thermal stress, such as during prolonged exercise in extreme heat or possibly if exercise is very strenuous, the body will be unable to meet the competing demands of the circulatory system and must decide whether to maintain energy requirements of muscles, or whether to facilitate cooling on the periphery. It is likely that when faced with conflicting demands, the body will favour blood flow to the muscles over temperature regulation (Nadel, 1979 and Noakes, 1992). As a result the body is in a compromised position because peripheral blood is not cooled. The end result is that while body heat production is increased, the ability to lose heat is decreased (Noakes, 1992).

It is well known that exposure to high environmental temperatures causes heart rate responses to be elevated under resting (Rowel, 1974; Pandolf **et al**., 1975), exercising (Lind, 1963; Suzuki, 1980; Wailgum and Paolone, 1984; Pivarnik **et al**., 1988, Sheffield-Moore **et al**., 1996) and recovery (Vogt **et al**., 1981) conditions.

Naturally the strain on the cardiovascular system is greater under “exercise-heat stress conditions” (Rowell, 1974). While exercise-heat stress places a greater stress on batsmen than thermal stress alone, it is likely that protective gear places an additional thermal load on the batsmen under high environmental stress conditions.

Increased physiological stress of protective garments has been attributed to the additional weight carried (Fox **et al**., 1966; Mathews **et al**., 1969; Ftaiti **et al**., 2001), disruptions to body movements and locomotion (Behman, 1984; Pascoe **et al**., 1994b), or additional thermal stress imposed by protective gear and multiple clothing layers (Mathews **et al**., 1969; Meir **et al**., 1994; Pascoe **et al**., 1994b). Mathews **et al**. (1969) identified that both the extra weight of American football gear and the reduction of skin surface area exposed to the environment were responsible for increased thermal strain. However, these authors believed that the disruption to the cooling process due to reduced surface area was the main factor responsible for higher heart rates.

A comprehensive review by Rowell (1974) identified that the cardiovascular and thermoregulatory responses to exercise have been extensively studied. However, it is obvious that the vast majority of research comprises maximal and sub-maximal continuous exercise, while few studies have been devoted to maximal bursts of intermittent activity (Nevill **et al**., 1995). In addition, studies examining the effects of clothing or protective garments on physiological responses have also tended to utilise trials involving continuous aerobic activity. Batting involves intermittent high intensity-anaerobic bursts of activity, therefore comparisons of responses with continuous-aerobic trials are problematic.

Several studies involving intermittent activity seem to indicate that higher environmental stress increases cardiac strain. Nevill **et al**. (1995) found that intermittent cycling involving maximal sprints under hot conditions (35 °C) resulted in significantly higher heart rates than under cool conditions (10 °C). Gore **et al**. (1993) simulated batting and bowling activities and examined trials that they believed characterised the upper range of work occurring in a first-class match. These authors found that mean heart rates, recorded over three sessions of batting, were significantly higher under conditions of 26.5 °C WBGT than under cooler conditions of 22.1 °C WBGT (129 ± 2 $bt.min^{-1}$ vs. 110 ± 2 $bt.min^{-1}$). Morris **et al**. (1998) also observed that for multiple sprint activities heart rates at the end of the exercise trial were higher under hot (30 °C) than moderate (20 °C) conditions. In contrast, Gore **et al**. (1993) found a reduction in bowlers' heart rates under hot conditions compared to the cooler environment. This was, however, explained as being due to some of the bowlers being injured and using a shortened run-up under the high environmental conditions. The studies mentioned above employed activities that differed in terms of mode, intensity and duration. Therefore direct comparison of cardiac responses between studies would be meaningless.

FLUID HOMEOSTASIS

FLUID BALANCE

During prolonged exposure to heat and/or physical exertion, regulation of body temperature takes precedence over regulation of body water, which will ultimately result in hypohydration. Thus in extreme environments (hot and humid), dehydration may often be driven far enough to be a threat to life, particularly if no fluid is available (Åstrand and Rodahl, 1977).

Total body water depends on body composition since adipose tissue is about 10% muscle and about 75% water (Sawka, 1988). Consequently about 40 to 70% of adult body mass comprises water (Sawka, 1992; Latzka and Montain, 1999), thus the body possesses a substantial buffer enabling it to cover any short-term losses (Åstrand and Rodahl, 1977). Nevertheless, any losses incurred must eventually be replaced, thus intake must at some point balance output.

Daily water loss may be accounted for by losses from gastrointestinal tract (faeces), respiratory tract (water vapour), skin (sensible and insensible perspiration) and kidney (urine), which typically may total about 2.60 L. This is balanced by intake of ingested liquids, water within consumed food and water liberated during metabolism (Åstrand and Rodahl, 1977).

During exercise-heat exposure body water is lost primarily through sweat output (Sawka, 1992), thus sensible sweat losses typically account for the majority of the fluid loss. Considerable losses occur during exercise, particularly when activity is prolonged in hot and/or humid environments. Naturally this occurs because evaporation of sweat is the body's primary means of dissipating excess heat under conditions of environmental heat stress.

Even though activity contributes to metabolic heat generation, Noakes (1992) observed that there are water reserves in the body that are mobilised as a result of physical activity. Metabolic water is produced as a by-product of metabolism. When food molecules (carbohydrates, fat and protein) are degraded for energy, CO_2 and water are formed. Metabolic water accounts for about 25% of the daily water requirements of a

sedentary person. Some water is stored in the muscle and liver in association with glycogen and is released when glycogen is utilised; for every gram of glycogen stored between 2.7 and 4 g of water are stored (Åstrand and Rodahl, 1977; Sawka, 1992). Intense anaerobic exercise of less than 90 to 120 seconds is reliant on the short-term energy system to provide fuel for muscular work (McArdle **et al**., 1991). The short-term system depends largely on glycogen stored in the specific muscles activated by exercise. When this glycogen is utilised, the tied up water is liberated and thus these substrate water stores in the muscle and liver may, to a small degree, compensate the sweat losses. However, at some stage after activity these glycogen depots must be restored, which will require additional water.

In cricket, batting activity often occurs over an extended period. An opening batsman's innings may last up to 3.5 hours during a one-day match, the total duration of which is interspersed with short periods of sprint activity, typically no longer than 6 to 8 seconds. Thus, batting is reliant on both aerobic and anaerobic energy systems throughout an innings (Noakes and Durandt, 2000), of which the relevant contribution is determined by the batsman's mode of activity. During sprint performances the ATP-CP and short-term energy systems utilise phosphagens (ATP-CP) and glycogen for energy. When glycogen is metabolised water is released. The significance of this with regard to fluid balance is two-fold. Firstly, players must ensure that their glycogen stores are fully "loaded" as well as being euhydrated prior to a game, which will provide them with a fluid reserve for competition. Secondly, at the end of a game or day’s play, it is essential that these glycogen stores (along with the necessary water) be replenished so that this substrate fluid reserve is replaced.

CONTROL OF SWEATING

The amount of fluid lost through sweating is dependent on the intensity of physical activity, the environmental stress, the clothing or gear worn and the activity levels (Sawka, 1988). In conditions of extreme heat, especially in combination with exercise, sweating and evaporation of sweat are essential to allow heat loss and body temperature regulation. As such the stimulation of sweat production is a reaction to elevated body temperature (Parsons, 2000). Continuous sweating, and the evaporation thereof, is a means by which to reduce or prevent elevations in body temperature. No single stimulus can be said to exert exclusive control over the sweating response. It has been suggested that the initiation of the sweating response and adjustments thereof are induced by both thermal (Nadel, 1979) and non-thermal (Manley, 1997) stimuli. These two controlling stimuli are themselves influenced by various internal and external factors. Thermal stimuli controlling the sweat response include the independent effects of central factors (core temperature) and peripheral factors (skin temperature) (Åstrand and Rodahl, 1977).

In terms of thermal stimuli, the initiation of the sweating response and control of sweat rate are determined by the internal temperature and skin temperature relationship. Nadel (1979) observed that sweating is initiated when core temperature reaches a certain threshold level. Above this threshold level some authors have commented that a linear relationship exists between core temperature and sweat rate (Saltin **et al**., 1968; Roberts and Wenger, 1979; Fortney and Vroman, 1985). Nadel (1979) suggests that skin temperature is responsible for determining the threshold level, whilst the rate of sweating at a particular temperature is proportional to the core temperature. Increasing the skin temperature results in a parallel shift in sweat rate linear to the core

temperature relationship (Fortney and Vroman, 1985), while skin cooling may have the opposite effect (Åstrand and Rodahl, 1977).

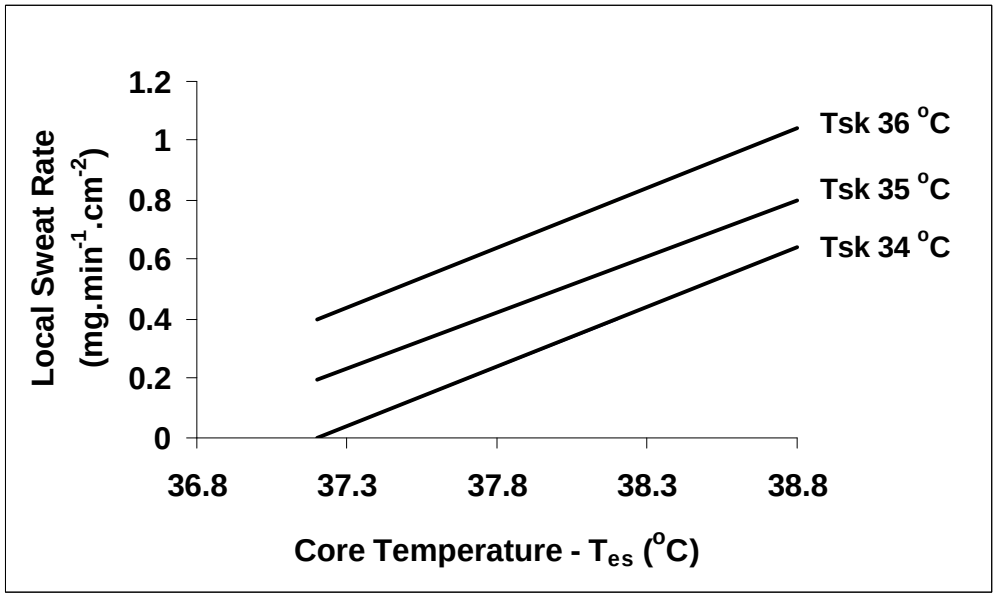


FIGURE 2: **Sweating rate as a function of internal and mean skin temperatures (Adapted from Nadel, 1979).**

Although sweat rate is proportional to core temperature, local sweat rates and thresholds differ (Nadel **et al**., 1971). Johnson (1991) found that different areas of the body appear to have different preferred temperatures and consequently begin sweating at different times. Under conditions where full sweating occurs, Berenson and Robertson (1973) suggest that the trunk and lower limbs provide 70 to 80% of the total moisture perspired. There are undoubtedly implications for cricket players, since these areas of the body are covered by the clothing and protective gear of the batsmen.

Naturally factors influencing the skin and core temperature relationship will alter sweat rates. These may include activity levels, environmental factors and the clothing or protective gear worn. It is observed from Figure 2 that when the temperature gradient between the core and the periphery is decreased, local sweat rate increases. This

occurs because of the decreased efficiency of dry heat loss, specifically conduction down the temperature gradient from the core to skin; it also means that greater demands are placed on evaporative processes. A reduction in the temperature gradient between the core and periphery has been observed (Wailgum and Paolone, 1984; Mathews **et al**., 1969) while wearing a football uniform. Similarly this gradient is reduced in athletic running apparel covering the whole body (Brownlie **et al**., 1987). Under protective wear the local skin temperature increases, with a resultant decrease in temperature gradient likely to occur. Consequently heat dissipation is affected, sweat rates increase, which ultimately results in greater levels of hypohydration.

The physiological mechanisms mediating the reduced sweating rate during hypohydration are not clearly defined. However, thermal stimuli are not the only agents responsible for mediating the sweat rate. The singular and combined effects of body fluid volume (Fortney **et al**., 1981; Fortney **et al**., 1988) and osmotic pressure (Harrison **et al**., 1978; Senay, 1979; Candas **et al**., 1986) of the blood are generally believed to modify the sweat rate. Also identified as a possible mediator is sympathetic nervous activity. These non-thermal influences contribute to the reduced sweating response during exercise-heat stress (Sawka, 1992).

Evidence of non-thermal influences affecting sweat rate is provided by the speed of sweating response, since there is an almost immediate, within seconds, response of starting or stopping exercise, a concomitant increase or decrease respectively in sweat rate (Åstrand and Rodahl, 1977; Gisolfi, 1983; Ayling, 1986). The speed of the initial sweating response to exercise would indicate that it is not a thermoregulatory one (Ayling, 1986).

MAGNITUDE AND RATE OF FLUID LOSS

In addition to the factors already identified as influencing sweat rate, Burke and Hawley (1997) and Latzka and Montain (1999) have noted that sweat rates among athletes vary considerably and are influenced by physical condition, acclimatisation, work duration and body size. Noakes (1992) points out that during endurance activities such as running, the most important factor determining the sweat rate is metabolic rate. The metabolic activity of runners is affected by running speed and body weight. Approximations of sweat rate in runners as influenced by metabolic activity are illustrated in Figure 3.

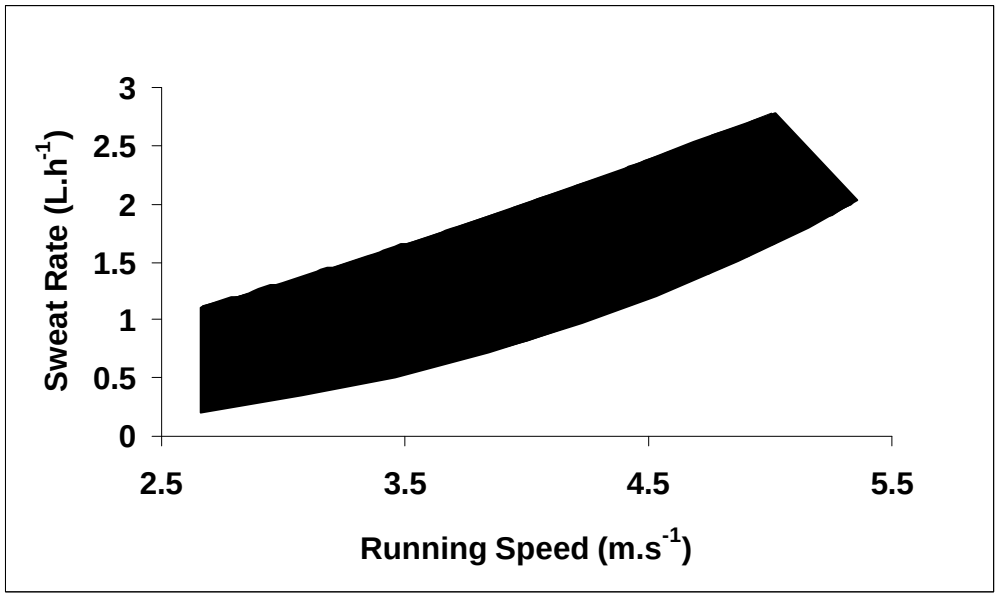


FIGURE 3: **Approximation of hourly sweat rates for runners, illustrating effect of metabolic activity on sweat rate (Adapted from Sawka and Pandolf, 1990).**

Sweat loss during long distance athletic events have been well documented and are typically around 1.0 to 1.2 $L.h^{-1}$ when conditions are temperate (Armstrong **et al**., 1985; Burke and Hawley, 1997). However, Armstrong **et al**. (1985) reported that in

hot and humid environments or when airflow is restricted, some individuals can sustain sweat rates of greater than 2.0 $L.h^{-1}$ during prolonged exercise. Pugh **et al**. (1967) have identified sweat losses of elite marathon runners frequently above 5 L per race, which represents hypohydration of 6 to 10% of body mass. The highest reported sweat rate discovered in the literature was 3.7 $L.h^{-1}$ (Armstrong **et al**., 1986) during an Olympic marathon. Noakes **et al**. (1988) have argued, however, that for slower endurance runners (marathon and ultra-marathon) the fluid loss rarely exceeds 0.5 $L.h^{-1}$.

During exercise-heat stress it is common for humans to dehydrate by 2 to 8% of their body mass (Adolph **et al**., 1947; Pugh **et al**., 1967; Armstrong **et al**., 1985). This figure will increase if an individual is well-conditioned and/or acclimatised; Allan and Wilson (1971) have shown increases of 10-20% in the sweat rate for these individuals. An acclimatised individual performing severe work is able to reach a sweat rate of 3 $L.h^{-1}$ and may average 12 L daily (McArdle **et al**., 1991).

In the heat, continuous exercise observes higher sweat rates compared to cooler environments (Armstrong **et al**., 1985). Similarly intermittent activities in hot conditions result in higher sweat rates. Fluid balance during prolonged intermittent high intensity shuttle running was measured by Morris **et al**. (1998). These authors found that the amount of body mass lost during hot (≈30 °C) and moderate (≈20 °C) conditions were 1.73 $L.h^{-1}$ and 1.13 $L.h^{-1}$ respectively.

TEAM SPORT AND CRICKET

Endurance activities like distance running are not the only ones in which large sweat outputs are observed. There are numerous other team sports that also experience large fluid losses during the course of a contest.

> "Team sports require players to perform multiple work-bouts at near maximal effort, punctuated with intervals of low intensity exercise or rest for the duration of the game. Such activity patterns are associated with a significant loss of body water which has a negative impact on physical and mental performance as well as temperature regulation" (Burke and Hawley, 1997, pp 38).

Continuous running studies suggest that fluid losses of greater than 1.5 $L.h^{-1}$ are considered large. Physical performance decrements have been seen at hypohydration levels as low as 1.0% of body mass (%BM) (Armstrong **et al**., 1985), while reductions of more than 2.0% BM are very likely to have performance implications. Studies of various team sports have reported sweat rates of greater than 1.5 $L.h^{-1}$, or an overall hypohydration of greater than 2.0% BM. These team activities include: Australian rules football (Pyke and Hahn, 1980; Pohl **et al**., 1981), cricket (Gore **et al**., 1993), rugby league (Meir **et al**., 1991), rugby union (Cohen **et al**., 1981), soccer (Mustafa and Mahamoud, 1979) and junior elite basketball (Broad **et al**., 1996).

Naturally sweat losses incurred during team sports such as cricket differ from those measured during prolonged continuous exercise (Burke and Hawley, 1997). The work rate (and therefore metabolic activity) in cricket play, especially batting, is intermittent and random in nature. Typically in cricket, as with other team sports, there is a high degree of inter- and intra-individual variability in work rates between players (Burke and Hawley, 1997). There are noticeable variations in the activity requirements according to the standard of competition, the type of activity (batting, bowling or fielding) and the style of play (fast bowler or spinner; aggressive or accumulator). In batsmen, different

styles of play may refer to batsmen who are “aggressive” and score the majority of their runs from boundaries, hence a lower work rate, while others score most of their runs by working the ball around and “accumulating” the bulk of their score from single runs (1s, 2s and 3s), thus a higher work rate. The batsman's body mass will also influence the metabolic rate, but this too is variable. Differences in stature, mass and body composition are common features amongst cricketers, and Stretch (1987 and 1991) has observed significant differences in these parameters between batsmen and bowlers. Due to the unpredictable and intermittent nature of batting activity and the considerable variability in batsmen's morphology, these cricket players are less able to anticipate sweat losses than athletes performing continuous activities. Clearly, determination of hourly sweat rates for batsmen is subject to considerable inconsistency.

As pointed out earlier, the game of cricket originated in temperate climates but is now played regularly in extremely unfavourable environments around the world. It is questionable whether the rules and regulations of cricket are always appropriate. Burke and Hawley (1997, pp 40) feel that:

> "Rules governing time of play, the length of play, length of play without rest and the uniforms and protective equipment for players may be suitable for cool environments, but they have not been adapted in recognition of the marked increase in heat load that occurs in hot environments."

However, increased awareness of the dangers of thermally stressful environments and the consequences of dehydration has seen amendments to the rules, allowing (but not enforcing) additional drinks breaks in hot conditions. The ICC Code of Conduct and Playing Conditions (1998) specify that the provisions of Law 16.6 (MCC, 1992) regarding drinks intervals during international matches are to be strictly adhered to,

"except that under conditions of extreme heat the umpires may permit extra intervals for drinks". The ICC regulations also make allowance for individual players to be given a drink either on the boundary edge or at the fall of a wicket on the field, provided no playing time is wasted.

Gore **et al**. (1993) measured fluid balance in cricket activities under several environmental conditions (Table V). Hotter conditions had a significant effect on sweat rate, with higher rates being observed. Differences in fluid balance between batsmen and bowlers were reported, with bowlers having greater rates of fluid loss. For the simulated cricket activity a combined (batsmen and bowlers) level of hypohydration of 0.3% BM was observed in cool conditions and 1.2% BM in warm conditions, while the match dehydration response of bowlers was of the order of 4.3% BM.

TABLE V: **Fluid balance measurements of elite cricket players. Modified from Gore** et al**. (1993).**

Players	Temperature (C°)	RH (%)	WBGT (C°)	Sweat Rate ($l.h^{-1}$)	Fluid Intake ($l.h^{-1}$)	Hypohydration (% BM)
Batsmen + Bowlers	23	65	22.1	0.54	0.43	0.3
Batsmen				0.47		
Bowlers				0.71		
Batsmen + Bowlers	33	22	26.4	0.6	0.51	1.2
Batsmen						
Bowlers				0.69		
Bowlers	33	30	27.1	1.37	0.53	4.3

Gore **et al**. (1993) did not examine batsmen under hot conditions, but their rate of fluid loss was 0.47 $L.h^{-1}$ and 0.6 $L.h^{-1}$ in cool and warm conditions respectively. These figures approximate the rate of a slow endurance runner and would not be considered extreme since they could be easily replaced in activity lasting an hour or so. By comparison, King and Christie (2001) and King **et al**. (2002) reported fluid

losses of 1.05 $L.h^{-1}$ (1.38% $BM.h^{-1}$) for a simulated batting work-bout under warm conditions. The intensity of this bout was designed to simulate one-day matches and was more intense than the aforementioned study. Using the data of King and co-workers, an estimate of the resultant level of hypohydration for a cricketer batting for 2.5 hours shows a hypohydration level of 3.5% BM, if no fluid was replaced. Voluntary replacement of fluid has been shown not to keep pace with losses (Adolph **et al**., 1947; Lithhead and Lind, 1964) and *ad libitum* drinking results in incomplete fluid replacement or voluntary dehydration (Hubbard **et al**., 1984; Greenleaf, 1992). Voluntary dehydration will result because, as Engell **et al**. (1987) suggest, thirst is a poor index of the body's water requirements. When typical fluid intake rates during cricket play are accounted for (Gore **et al**., 1993), an overall hypohydration level of 1.8% BM would be attained. Thus a batter opening the innings in a one-day match may be in a hypohydrated state of nearly 2% while there is still an hour left to bat in the innings.

Since cricketers are often all-rounders, there is the likelihood of players becoming substantially dehydrated whilst fielding and bowling. During this phase of play fluid replacement is always difficult. On completion of an innings, the all-rounder may be required to bat before he has been able to rehydrate adequately, thus his level of hypohydration may be greater than 2% of BM, resulting in performance decrements.

HYPOHYDRATION AND PERFORMANCE

There is a large body of literature implicating hypohydration as adversely affecting physical and mental performance. The majority of the work involving exercise performance and dehydration has focused on moderate-to-high intensity continuous

exercise of prolonged duration. There are, however, few hypohydration investigations utilising intermittent high-intensity exercise. During continuous exercise various physiological processes are disrupted by hypohydration. Dehydration has been shown to increase rectal temperature, increase cardiovascular strain and reduce sweat response (Ekblom **et al**., 1970; Sproles **et al**., 1976; Sawka **et al**., 1983; Montain **et al**., 1998) and skin blood flow (Fortney **et al**., 1983), in addition to increased perception of effort while working (McGregor **et al**., 1999), increased muscular fatigue (Bigard **et al**., 2001) and impaired mental and cognitive function (Gopinathan **et al**., 1988; Cian **et al**., 2001). Some of these processes have been suggested as mechanisms responsible for impaired performance. Whatever the reasons for impaired performances, it seems fairly clear that hypohydration of 2% of body mass is the critical level at which significant physical and mental performance deficits occur (Latzka and Montain, 1999), a deterioration that King **et al**. (2002) feel is sufficient to advocate that cricketers are educated about effective hydration strategies.

One of the physical requirements of batters, particularly in limited over matches, involves the capacity to perform repeated bursts of intermittent activity, sometimes over a period of 45 to 50 overs. Even though performance of aerobic activities are widely known to decline with dehydration, it is unclear whether similar deteriorations will occur for intermittent activities such as batting. In addition batting performance is determined by more than pure physical capabilities; motor and psychological skills are also important performance criteria (Stretch **et al**., 2000). Recently McGregor **et al**. (1999) found that performances in a soccer skills test decreased following prolonged intermittent shuttle running when no fluid was ingested. They also

observed changes in various other responses during shuttle runs, which included increases in heart rates, perceived exertion, serum osmolality, sodium and cortisol concentrations.

PERCEPTION

Physical thermal stress undoubtedly influences the physiological processes of an individual, but the effect of these stressors on perceptual responses also needs to be considered. According to Gunnar Borg (1970), “man reacts to the world as he perceives it, not as it really is” and Kerslake (1972) argued that any departure from an individual’s perception of thermal comfort is likely to be attended by some deterioration in task performance. Therefore to attain a holistic understanding of the cricketer’s response to the situational demands, Parsons (1993) suggests that it is necessary to examine more than just physiological responses or physical conditions one must incorporate a psychological component. Perception involves the integration and interaction of physiological, physical and psychological variables. Several perceptual variables were considered in the present study, namely perceived exertion, thermal sensation and thermal comfort.

PERFORMANCE

In addition to the performance decrements attributed to hypohydration, heat stress is also known to have an effect on performance. However, the effect of thermal stress on performance outcome is inconsistent (Ramsey, 1995). Several studies have reported that performance loss under extreme conditions is minimal or non-existent (Grether **et al**., 1971; Ramsey and Pai, 1975), while other investigations have shown performance decrements (Azer **et al**., 1972; Fine and Kobrick, 1978; Beshir and

El-Sabagh, 1981). It is essential to realise that these were not athletically orientated studies, which tend to examine physical and physiological determinants of performance, but were occupationally based and investigated a variety of cognitive and perceptual motor tasks. A more comprehensive picture is provided in the meta-analytical review by Pilcher **et al**. (2002). They found that temperatures of between 21.1 and 26.6 °C WBGT had very little effect on performance, but above 26.6 °C the environment had a significant effect, particularly for attentional and perceptual type tasks, both of which are relevant to batting. These authors also identified that heat exposure of more than an hour resulted in a substantial detriment in performance.

Batting is an activity that relies on various physical, perceptual motor, cognitive and menal capabilities, all of which must be synchronised for a skilled performance to occur. Since hypohydration has been shown to impair physical performance as well as mental and cognitive function, and heat stress is known to impair performance tasks, it is plausible that cricket performance, or the ability to sustain a high standard of performance, would likewise be degraded. However, the impacts of various factors, in this case environment and clothing, which influence man's thermal environment and his perception thereof must be empirically investigated to determine if there is in fact a change in batting performance.

Both the perceptual responses and performance outcomes were examined in the present study in order to establish a holistic profile of cricketers' responses to playing under varying conditions.

CHAPTER III

METHODS

INTRODUCTION

This study comprises elements of a field study and a laboratory simulation. The aim of the study was to determine the physiological, psycho-physical and performance responses during one-day batting activity, as well as consider the impact of the environment and protective gear. Unfortunately attempting to monitor cricketers' thermophysiological responses during one-day matches is difficult, therefore a one-day batting simulation was carried out. Since certain aspects of batting are unpredictable and random in nature, simulating the actual match conditions was problematic. Fortunately, certain parameters of the one-day game are relatively constant and consequently a general pattern and intensity of work was identified (King, 2001). It is this general model of one-day batting activity, that the present study examined.

PILOT TESTING

Prior to testing, extensive investigative trials were conducted. One of the first steps was to determine a suitable work-bout to be used. The first pilot observed one-day international (ODI) matches to determine an appropriate work-bout. Following this work, several further pre-pilots were conducted to establish the testing protocol for this work-bout and the suitability of equipment and rating scales to be used.

DEVELOPMENT OF WORK-BOUT

The batting specific work-bout selected for the present study was based on observations of matches played at the 1999 Cricket World Cup, involving South Africa, West Indies, Sri Lanka, India, Pakistan and Zimbabwe. There were also observations

made from specific “high scoring” ODI innings, from matches played between 1999 and 2001. High scoring innings involve situations where 260 runs or more were scored in the allotted Overs. Observations included the duration between deliveries, duration between Overs, the mean number of runs scored (actually "sprinted") per Over and the mean of the runs scored in high scoring matches. Naturally the data are relevant to one-day international cricket and not four-day and five-day cricket typically played at first-class and test level. These examinations describe the higher intensity (Noakes and Durandt, 2000) at which one-day cricket is played by comparison to longer versions of the game.

The average duration of these identified periods (Table VI) are similar to those observed by Fletcher (1955). However, the nature of the game influences these durations, thus emphasising the unpredictable character of the game and the randomness of work-rest cycles in batting. Numerous elements of the game, outside of scheduled interruptions, influence the temporal characteristics of play. These include the fall of wickets, clothing adjustments, occurrence of injuries, boundaries and runs scored including extras, television replays, the type of bowler (i.e. length of run-up) and other extraneous interruptions such as crowd interference. All of these factors will influence the batsman’s activity pattern during play.

TABLE VI: **Work rate data from ODI data indicating work-rest duration whilst batting.**

		Period of Play			
		Innings	*Over 0-15*	*Over 16-45*	*Over 46-50*
Mean Duration (s)	Between Deliveries	31	36	31	-
	Between Overs	58	63	56	65
Mean number of “runs” per Over		2.22	1.4	2.25	4.3
Mean of high scoring innings		3.99	-	-	-

The mean number of “runs” scored per Over examines only the runs actually sprinted (not boundaries), namely ones, twos, threes and possibly four or more. These runs include runs scored from the bat, leg byes and byes, note that runs are not always sprinted at full pace, which gives an indication of the players’ work rates at various stages of the innings. Theoretically runs scored from boundaries would not require players to run. However, in practice a player may complete one, two or three sprinted runs before the ball actually crosses the boundary. As a result, players are performing work and expending energy during these periods. The results indicate that the duration between deliveries, irrespective of the type of bowler, is about 30 s, while the approximate duration of the break between each Over is a minute. Players will sprint on average two singles an Over for the entire duration of the game, although in certain high scoring matches the work rate is doubled and players complete four singles per Over for the duration of the innings. Since the latter results were compiled from matches in which over 260 runs were scored, it is evident that considerable distances were covered at a high intensity. Due to the current rules that apply to the fielding team, it is generally observed that the batting team’s innings is segmented and batting tactics differ according to a particular section of an innings. The innings can be compartmentalised into two distinct sectors, namely 1 to 15 Overs and 16 to 50 Overs with the latter at times being strategically subdivided even further. During the first section there are more players close to the bat, therefore batters look to acquire a greater portion of their runs from boundaries (i.e. less running). In the latter segment fielding restrictions are partially lifted and more fielders are available to protect the boundary, thus more openings in the field are available and the players will accumulate more of their runs from singles. Therefore in high scoring matches, from the 16th Over onwards batsmen may run in excess of four singles per Over.

THE WORK-BOUT

The standardised batting work-bout required subjects to bat while facing deliveries projected from a BRELL bowling machine with the speed set at level 6. The actual velocity was not determinable. Subjects received one delivery every 30 s with a total of 7 Overs (42 deliveries) faced. After every three deliveries the subject was required to perform one shuttle run bout, at full pace. Batsmen ran between the two popping creases set 17.68 m apart, the same distance as a cricket pitch. Each shuttle bout required batters to run to the opposite popping crease and then return. When subjects reached the opposite popping crease they had to ensure that the bat crossed the line before returning to their starting position. The 4 singles run per Over simulated the high work rate that is likely to be carried out after the 15^{th} Over in a high scoring match. The ball used was not a regulation hard leather cricket ball but rather a softer leather-covered action cricket ball to prevent impact injury during conditions where limited protective gear was worn.

The 28 pitch-lengths run by the subjects was a cumulative distance of approximately 495 m. There was a 30 s period of inactivity between deliveries, theoretically when the bowler walks back to "his mark". The 1-min period between each Over (every 6 balls received) was used to collect some of the data. This break or rest period was designed to simulate the wait period in cricket between Overs, when the next bowler prepares to bowl.

EXPERIMENTAL CONDITIONS

ENVIRONMENTAL CONDITIONS

Subjects were tested under two climatic test conditions, these were considered either High (H) or Low (L) environmental stress. Testing of High and Low stress conditions was "typically" carried out in different seasons. The High and Low environments were categorised according to WBGT index. These WBGT categories (Table VII) were selected on the basis of the ACSM (1985) guidelines for the prevention of thermal injuries in running (Table I). They were also generally related to typical environmental temperatures observed in cricket regions possessing favourable and unfavourable conditions (Gore **et al**., 1993; King and Christie, 2001). High categories were considered any WBGT above 23 °C and Low was a WBGT below 18 °C.

TABLE VII: **High and Low environmental stress limits.**

LIMITS	WBGT (°C)
High	**>23 °C**
Intermediate	18 to 23 °C
Low	**<18 °C**

WBGT was the preferred method for evaluating environmental heat stress because the index considers all four of the basic environmental factors influencing the thermal conditions. Other methods may not be as comprehensive in this regard.

CLOTHING CONDITIONS

Two clothing conditions were imposed in this investigation, consisting of Full batting Gear (FG) and No batting Gear (NG). The Full-Gear condition required subjects to wear standard cricket gear worn by cricketers at first class and test level. The Full-Gear

clothing ensemble, as shown Figure 4, consisted of general clothing (shoes, socks, underwear, pants and cricket shirt), the protective batting gear (batting pads, gloves, abdominal protector, thigh guard, inside thigh guard, elbow guard and helmet), and subjects also carried a bat.

FIGURE 4: General and protective clothing ensembles used.

Cricket clothing produced by different manufactures is by and large similar, and as such subjects provided their own general clothing, as well as abdominal guard. Subjects were instructed to bring cotton or polyester long pants and short sleeve shirts, if possible more than one shirt. All the subjects used a set of standardised protective batting gear. The overall mass of the gear was approximately 9.3 kg and 10.8 kg including bat. The No-Gear condition entailed the investigation of subjects while wearing only the general cricket clothing without protective gear, but the bat was carried. During testing both clothing conditions were examined during each of the High and Low stress conditions, although the order of investigation was randomised.

EQUIPMENT PROTOCOL

DEMOGRAPHIC AND ANTHROPOMETRIC MEASUREMENTS

At the initial testing session, general demographic data were obtained for each subject, including age, standard of performance and activity levels. Morphological data were also collected, consisting of stature and mass from which body surface area (BSA), body mass index (BMI) and reciprocal ponderal index (RPI) were calculated. In addition body composition estimates were made using bioelectrical impedance analysis (BIA). The general data collection form for demographic and anthropometrical data is shown in Appendix B.

Stature, Mass, BSA, BMI and RPI

A calibrated Holtain stadiometer was used to measure stature, which was accurate to the nearest millimetre. Body mass was measured using a previously calibrated Toledo® electronic scale, model 8142 (Trek Scale Company, Cleveland) and recorded to the nearest 0.01kg. Subjects were weighed in underwear only. Height and mass were used to determine BSA, BMI and RPI. The BSA of a nude human was calculated using the DuBois method (1915) as follows:

$$BSA\ nude\ (m^2) = 0.202\ (M^{0.425} \times S^{0.725})$$

The calculation of BMI and RPI is as follows:

$$BMI\ (kg.m^{-2}) = \frac{M}{S^2}$$

$$RPI\ (mm.\sqrt[3]{kg^{-1}}) = \frac{S}{\sqrt[3]{M}} \times 1000\ mm.m^{-1}$$

Where: M = body Mass (kg)

S = Stature (cm)

Body Composition – Bioelectrical Impedance Analysis (BIA)

Bioelectrical impedance analysis provides an indirect method of determining body composition that is non-invasive and allows for rapid measurements. McArdle **et al.** (1991) indicate that BIA has been correlated with high accuracy against densiometry (hydrostatic weighing) and other techniques. It has been validated in normal and obese adults, children and in clinical settings.

Testing procedures followed established guidelines. Subjects were assessed barefoot, lying on a non-conductive surface, legs abducted at an angle of 30° to 45° from the trunk. The BIA unit consists of four electrodes placed on the hands and feet. Positioning of electrodes on the hands and feet was done according to the method of Hoffer **et al.** (1969). The impedance value obtained was converted to percent fat by an equation formula within the BIA system. Derived variables of interest were percent fat (% Fat), lean body mass (LBM) and fat mass (FM).

PHYSIOLOGICAL PARAMETERS

Selected physiological variables associated with human thermoregulation were measured. These included measurements of body temperature, cardiac activity and fluid loss. Temperature variables consisted of peripheral temperature responses from which mean skin temperature was calculated. Circulatory factors involve average and peak heart rate responses. Hydration measures considered absolute and relative sweat losses and sweat rates.

Skin Temperature Measurement

Skin temperature measurements were taken from thermistors placed on the skin in standardised locations according to the method of Burton (Parsons, 1993). The locations for assessment included the chest, forearm and shin as indicated. However, an additional site was monitored with a sensor placed on the forehead (sites are depicted in Figures 5 and 6). In the cases of right-handed batsmen, skin sensors were placed on the left side of the body, while for left-handed batsmen, sensors were placed on the opposite side. Prior to testing sites were marked in order to standardise the placement of thermistor locations during each testing session. Once thermistors were in place they were secured with vapour permeable tape, Fixomull® Stretch (BSN medical, Hamburg). Under certain conditions the thermistors were covered by protective gear and/or clothing. The electrode sensor leads were secured with adhesive tape so as to prevent entanglement and to allow unrestricted movement of the subject when performing the batting activity. Standard (ET-016) general thermistor probes (ACR Instruments, Canada) were used to record temperature.

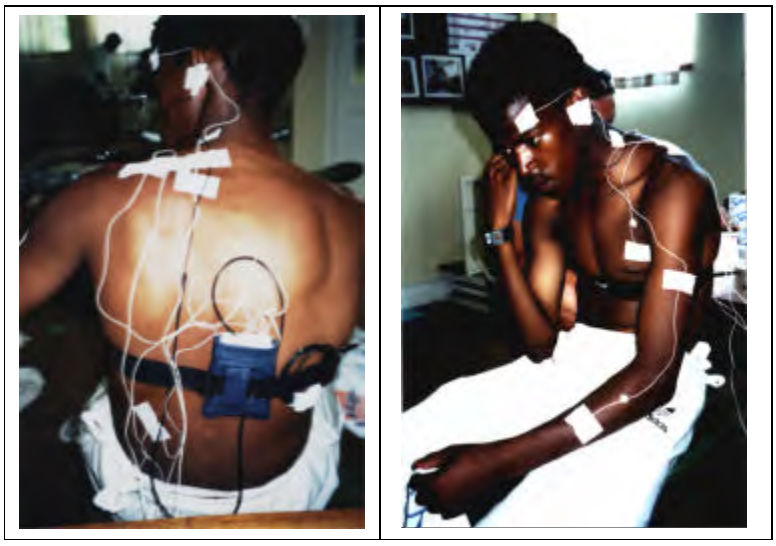
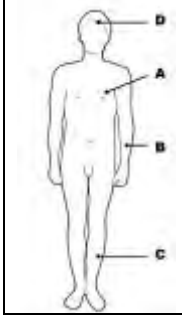


FIGURE 5: **Placement method and securing of skin temperature sensors.**

The skin temperature probes were factory calibrated prior to experimentation. Their accuracy was checked several times throughout the study to ensure that readings were precise. The accuracy was confirmed in a water bath over a temperature range of 29 to 42 °C and was accurate to within 0.1 °C.

Monitoring Skin Temperatures

All temperature sensors were connected to an eight-channel ACR datalogger (ACR Instruments, Canada), although only five channels were used. Channel 1 logged ambient temperature and skin temperatures were recorded on channels 2 to 5. This device continuously monitored temperature readings from the various sensors and all data were logged simultaneously. The sample rate was set at 60 s.



Skin Temperature Sensor Placement

A) Chest – midway between the nipple and auxilla.
B) Forearm – on the dorsal surface of the forearm midway between the olecranon and the styloid process.
C) Shin – on the antero lateral aspect of the leg midway between the lateral condyle of the femur and the lateral maleolus.
D) Head – on the frontal portion of the head approximately 20 to 30 mm above and lateral to the supraorbital margin in close proximity to the hairline.

FIGURE 6: **Diagram of skin temperature sites and description of placement.**

The sensors were attached to the logger, which was placed in a material carry case. The case was fixed to the heart rate monitor strap and positioned in the centre of the subject's back (Figure 5). When all the trials had been conducted the data were downloaded to a personal computer (PC) via the loggers interface unit. These data were stored and the results further analysed. The logger case was 107 mm x 74 mm x 22 mm, with a mass of 110 g. Its operating limits are -45 °C to 70 °C, 0 to 95% RH with clock accuracy of approximately 8 s per day.

Mean skin temperature (MST) was calculated from the weighted average of the chest, forearm and shin sites (Parsons, 1993). The weighting of these sites are shown in Table VIII and sample calculations are represented in Appendix C. The forehead temperature was used to provide additional information regarding thermal state beneath the helmet.

TABLE VIII: **The anatomical locations and weighting of skin temperature sensor sites for the calculation of mean skin temperature.**

	SITE	WEIGHTING
A	Upper chest	0.50
B	Outer mid lower arm	0.35
C	Shin	0.14
D	Forehead	-

Note: The sites used to determine mean skin temperature are highlighted.

All temperature parameters (chest, forearm, shin, MST and forehead) were measured throughout each trial and are expressed as average data for the entire bout and mean temperature for each of the 7 Overs. Each Over, including between Over and between delivery periods, was approximately 3.5 min. Consequently three samples were taken during each period to provide an average temperature for a particular Over.

Circulatory Responses – Polar Heart Rate Monitor

Oxygen consumption (VO_2) can be indirectly estimated from heart rate (Morgan and Bennett, 1976). Oxygen consumption is an indication of energy expenditure and therefore heat production. However, the relationship between heart rate and VO_2 is more relevant to steady state exercise, whereas the nature of physical exertion in this

batting work-bout was high intensity and intermittent. The study examined cardiac responses in order to indicate metabolic requirements of cricket activity and the cardiac strain experienced due to exercise and thermal stress.

Cardiac frequency was assessed via a Polar Accurex Plus Heart Rate Monitor (Polar Electro, Finland). These monitors utilise the electrical activity of the heart to measure and store heart rate data. The system is comprised of the watch (receiver), the transmitter and electrode strap. The heart watch serves as a display unit allowing various functions to be programmed and to store the collected data. The watch receiver was worn on the subject's wrist to ensure that it remained within the range of the transmitter. The monitor was fitted according to the manufacturer's specifications. However, adhesive tape was also applied to prevent slippage. The monitor's signals were coded for each subject to prevent interference.

The monitor was set to sample cardiac activity every 5 s during the work-bouts and recovery periods. Data were recorded on the wrist receiver while the timing of each event was manually recorded on the data sheets. The heart rate monitor watch was synchronised with that of the research team so that downloaded data were related to events during testing. The following heart rate variables were gathered: baseline, anticipatory, average exercise, mean of each Over, peak exercise and recovery heart rate. These data were expressed in absolute terms not as a percentage of age predicted maximum heart rate.

Baseline heart rate was established from data collected at each of the data collection sessions. As a result of the normal variability in resting heart rate, Durant **et al**. (1992)

suggest that three measures of resting heart rate are needed to achieve reliability above 0.9. On this basis three baseline heart rate recordings were taken, one recording from each testing session, and the mean was used in the analyses. On test days, once fitted with heart rate monitors, subjects were required to lie in a supine position for 3 to 5 min in order to obtain a stable baseline heart rate record. The anticipatory heart rate was collected just prior to the batting trials. This only occurred once players had completed a warm-up and were ready to commence with the trial. While the average exercise heart rate was the overall average of the values recorded over the entire exercise period, including the between delivery and between Over period, mean exercise heart rate for each Over was the mean of the values recorded during each of the 7 Overs. Peak exercise heart rate was the highest attained during the entire work-bout. The recovery heart rate was deemed to be the cardiac responses recorded after termination of the work-bout and the subject had actively recovered for 40 min. Active recovery consisted of subjects collecting balls and operating the bowling machine while the other subjects completed their trials. The recovery heart rate was separated into eight periods. The mean of each subsequent 5-min period provided the eight recovery intervals 1-5, 6-10, 11-15, 16-20, 21-25, 26-30, 31-35 and 36-40 min respectively. Five minutes is the approximate duration of a drinks interval, 10 min the length of an innings change, 20 min the duration of tea and 40 to 45 min the duration of lunch.

The data collected during the work-bout and recovery period on the wrist receiver were taken to the laboratory and downloaded onto a PC via the Polar Interface Plus System™ (Polar Electro, Finland) for Windows™ (Microsoft Corporation). A printout of the subject's pulse rate curve and pulse listing was obtained from the data collected on the heart watch (Appendix C). Thus data from the pulse listing were used to determine

the various heart rate variables. Downloaded data were put onto computer so that all the data could be statistically analysed.

Fluid Balance and Sweat Rate

Fluid balance is dependent on fluid loss and fluid gain. While performing exercise, by and large the greatest contributor or rather distributor to the total water loss is that incurred by sweat loss. Total water loss during activity can easily be calculated by observing changes in body mass (BM). By assigning a density of 1.0 $g.ml^{-1}$ to water, a simple method of estimating Sweat Loss (SL) was possible, expressed as:

$$SL\ (L) = [BM\ before\ activity\ (kg) - BM\ after\ activity\ (kg)] / g.ml^{-1}$$

This provided an absolute value of sweat loss during activity.

Note that this figure of sweat loss does not distinguish between losses incurred from sensible or insensible perspiration.

The Relative Sweat Loss (SL_{REL}) was calculated by dividing absolute sweat loss by BM before activity and multiplying by 100. Note that 1 kg is equal to 1 L.

$$SL_{REL}\ (\%\ BM) = [SL\ (L) / BM\ before\ (kg)] \times 100\ kg.L^{-1}$$

The Absolute Rate of Sweat Loss (SL_{RATE}) was estimated by dividing the absolute quantity lost by the duration of the activity (min) multiplied by 60 min to provide a figure in $L.h^{-1}$ as follows:

$$SL_{RATE}\ (L.h^{-1}) = [SL\ (L) / Duration\ of\ Work\text{-}bout\ (min)] \times 60\ min.h^{-1}$$

The Relative Rate of Sweat Loss ($SL_{RELRATE}$) was determined by dividing relative sweat loss by the duration of physical exertion body and multiplying by 60 min, as follows:

$$SL_{RELRATE} (\% BM.h^{-1}) = [SL_{REL} (\% BM)/ \text{work-bout duration (min)}] \times 60 \text{ min}.h^{-1}$$

Change in body mass over the exercise period was calculated by weighing the subjects in underwear only, before the work-bout and immediately on completion. During the pilot investigations the clothing and gear was weighed before and after each work-bout to determine sweat accumulation in these items, but it was shown to be negligible.

Estimating SL_{RATE} from the duration between the initial and final weighing was problematic since this period also accounted for the time taken to fit sensors and perform a psycho-motor performance task, all of which occurred prior to the subject moving outside to the test area. It was assumed that the loss of fluid during instrument fitting and performance testing in a thermo-neutral environment (indoor) was negligible. As such the period from when the subject moved outside to the test area until final weighing was considered the duration of the test and utilised to estimate the SL_{RATE}.

Subjects were not permitted fluid during the work-bout; however, they were permitted to consume fluid *ad libitum* and void urine during the rest period. Subjects were asked to arrive in a euhydrated state on the day of testing. They were advised to drink a minimum of 500 ml of fluid (water) the evening prior to testing. All subjects followed a pre-exercise euhydration procedure at the start of each test day. The procedure-involved subjects consuming 500 ml of water approximately an hour before testing.

PERCEPTUAL PARAMETERS

To gain an understanding of the cricketers' perceptual responses to the activity performed, several psycho-physical indices were monitored. These perceptual indices included ratings of perceived exertion (RPE), thermal sensation and thermal comfort.

Rating of Perceived Exertion (RPE)

Borg's (1982) rating scale of perceived exertion was used to determine how subjects felt during the activity. RPE is a 15-grade rating scale ranging from a minimum rating of 6 to a maximum of 20 (Appendix B). The RPE assigns a verbal anchor to each rating; these anchors indicate how individuals felt during activity and ranged from "very, very light" to "very, very hard". It is a scale that is easily understandable and usable, both to the researcher and the subject.

The conceptual basis and use of the RPE scale was carefully explained to all subjects prior to testing (Appendix B). During the test subjects were required to rate the work-bout on the numerical scale in order to indicate their level of exertion. Subjects were asked for a general rating, which referred to their overall perception of how physically taxing they felt the task was. Perceived exertion was recorded after every Over (every 6 balls faced) and data collection occurred during the period of inactivity between Overs. Average RPE refers to the overall average of RPE responses reported over the entire bout. Mean RPE for each Over was the mean of values collected during each of the 7 Overs.

Thermal Sensation and Thermal Comfort

An individual's perception of effort may well integrate environmental factors such as thermal sensation and comfort; however, to isolate the individualised perception of the thermal characteristics of the environment, ratings of sensation and comfort were collected during each work-bout. Responses were recorded at the same time as RPE measurements. The thermal sensation scale used was the ASHRAE (1966) sensation scale and ratings were given on a 7-point scale, where 1 refers to "cold", 4 to "neutral" and 7 to "hot". Subjects were then required to rate thermal comfort on a 3-point scale whereby they indicated if they would be more comfortable if it were "cooler" (1), "warmer" (2) or if they were thermally comfortable and did not desire a change in temperature (3). Both scales are presented in Appendix B. Thermal sensation was reported as an average for the entire bout and as mean values for each Over, in the same manner as RPE. The overall incidences of thermal sensation and thermal comfort ratings, expressed as a percentage were also reported.

PERFORMANCE PARAMETERS

Performance Measures

The performance categories examined in the present investigation were speed, agility, sprint repeatability, and batting specific reaction time.

Speed, Agility and Sprint Repeatability – Speed Timer Sensors

Timing each sprint set and segments thereof assessed agility, speed and sprint repeatability during the work-bout. Every sprint set executed as part of the work-bout was timed using a sprint timer system consisting of LED sensors (switch) placed at either end of the wicket and connected to a timing device. The timing system and

software was developed by the Department of Human Kinetics and Ergonomics (Rhodes University) for use in this study. The switches were mounted on wooden stands at a height of 1.2 m and were placed at either end of the wicket 2.5 m from the popping creases at the batting and bowling ends respectively. Each switch consisted of a LED transmitter and receiver, which were placed opposite each other across the width of the pitch (Figure 7). Thus a subject running the length of the pitch would have to pass between the sensors. When performing a sprint set, the batsmen would pass between both sets of switches while running toward the bowling crease and then returning to the batting area.

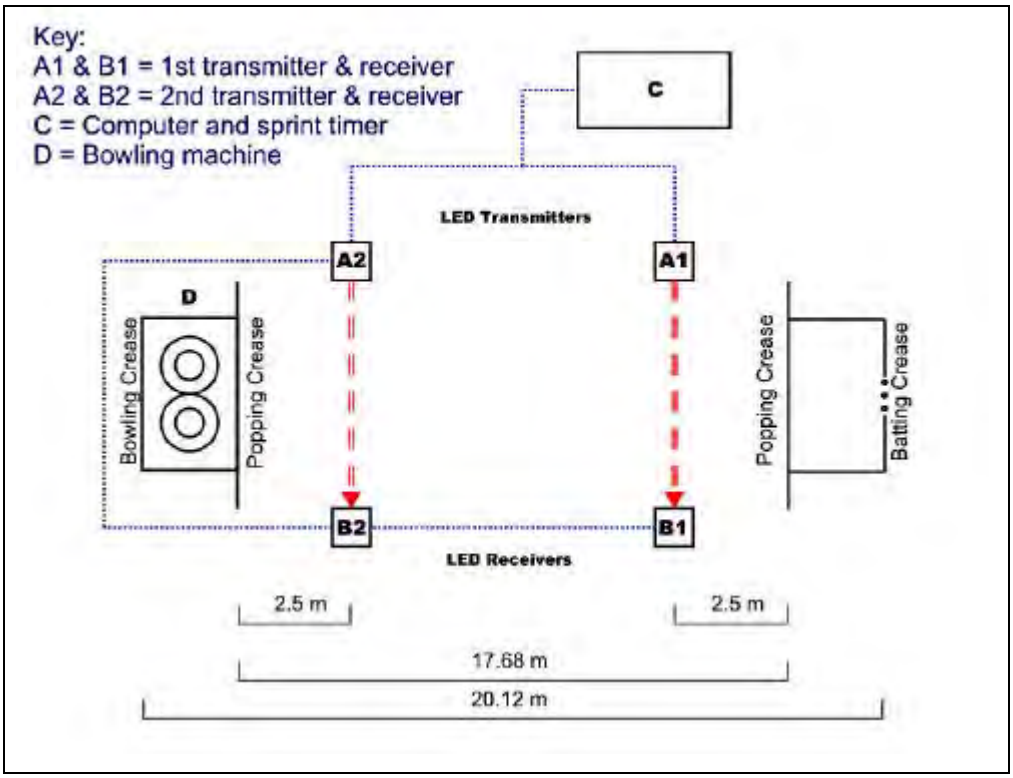


FIGURE 7: **Schematic of sprint timer set-up on the test area.**

As the batsmen passed between the sensors they would break the signal between the transmitter and receiver, and trigger the timer switches on or off. The timing device measured the various sprint and agility times. The durations of each sprint set were

recorded and fractioned as follows: SPRINT 1, TURN, SPRINT 2 and OVERALL. SPRINT 1 was the time taken to move from the first switch (batting area) to the second switch (bowling area), and similarly SPRINT 2 was the time taken to return from switch 2 back to switch 1. These measures represented sprint speed. TURN was the time taken to move between the second set of sensors, place the bat over the popping crease and then return through the same switch, hence an indication of the turn time or agility. The last measure was a combination of all the times involved in performing the sprint set (SPRINT 1, TURN, SPRINT 2) and gave an indication of the OVERALL time taken to perform the each sprint set. The four sprint performance variables were presented as mean values of responses recorded over the entire work-bout. Thus measures of sprint speed and agility were obtained from the required run between the creases. Sprint repeatability was determined by noting the variance in sprint times over the test duration.

Reaction Times – Batting Specific Reaction Test

Batting requires players to face deliveries being propelled at them at speeds of up to 40.2 $m.s^{-1}$ (Abernethy, 1981) over a distance of approximately 18 m. At this velocity batsmen have very little time to react, about 0.45 s. Batters must make a decision on how to play the ball and they must also move into a position to enable them to execute the chosen (desired) stroke. As a general rule the batsman will observe the delivery and then choose whether to go "forward" or "backward" to play the ball. Once the batsman has chosen the correct length he must then move to that position. The speed with which this decision is made and the speed of execution of the movement will impact on the success of the stroke. Naturally reaction time and movement time are not the only

factors influencing the success of the shot played. However, if an individual is slow to react or slow to move then the likelihood of a skilled performance will deteriorate.

Using the TKK 1264-II Whole Body Reaction Measuring System (Takei and Company, LTD, Japan), a test was developed to evaluate batting-type movement responses. This batting specific reaction test assessed the cricketer's choice reaction time. The test was carried out indoors and was performed just before (pre-reaction time) and immediately after (post-reaction time) each batting trial. The reaction test was intended to mimic, on a very basic level, the procedure involved when a delivery is bowled and the batsman must render a decision to move either forward or back.

A schematic diagram of the apparatus used to record the choice reaction time and movement time is presented in Figure 8. The test involved subjects positioning themselves with both feet on the reaction mat, assuming a natural batting stance and facing a light stimulus presentation unit. The light was placed a distance of 9 m from the mat at a height of 2 m. The height simulated the point of release of a delivery from a bowler. Once the optical stimulus was presented (A), instantaneous flashing of a red or blue xenon lamp, subjects would react. Based on the stimulus offered, subjects made a choice to move either "forward" or "backward". The red light represented a “full” delivery and therefore signalled the player to initiate a movement forward (D), while the blue light was indicative of a short pitched delivery and signalled a player to shift backward (E). Once a stimulus was presented, the subject was required to move the entire body off the mat (B) for the device to record the reaction time. Subjects were instructed to jump with both feet off the mat when moving back or forward.

Each trial required batters to react to 10 randomly presented stimuli (5 forward and 5 backward). The experimenter manipulated the presentation of the light stimuli at the control consol (C). All times were manually recorded and the average of the pre- and post-reaction times from each trial were analysed. Subjects were familiarised with the task before testing sessions. At the start of each test day they completed a number of familiarisation trials before the test proper started.

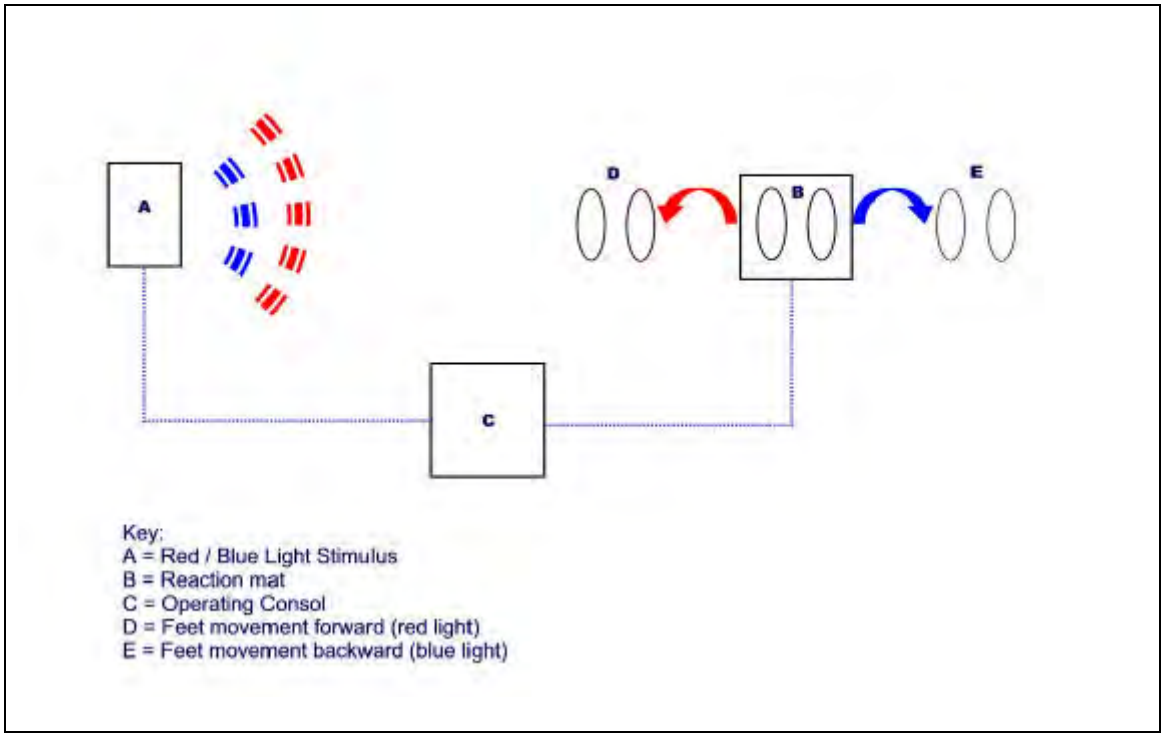


FIGURE 8: **Set-up of instrumentation to measure choice reaction and movement time.**

ENVIRONMENTAL INSTRUMENTATION

The relative humidity was measured by an electronic thermo-hygrometer. A Masons Hygrometer was used to measure ambient temperature (T_A) and naturally aspirated wet bulb temperature (T_{NW}). The hygrometer consisted of a standard thermometer and a natural wet bulb thermometer, both accurate to within 0.1 °C. Globe or mean radiant temperature (T_G) was measured with a thermometer encased in a black globe

(diameter 150 mm). The three environmental temperature measures were then used to calculate the WBGT index as follows:

$$WBGT\ (°C) = 0.7 \times T_{NW} + 0.2 \times T_G + 0.1 \times T_A$$

Sensors (T_A, T_{NW}, and RH) were housed in a Stevenson screen that was positioned on the test area within 3 m of the subjects' batting position. The screen was placed at a height of 1.2 m. The globe thermometer was situated outside the screen in direct sunlight at the same height as the screen.

TEST AREAS

The outdoor "field" test site, where the cricket specific work-bout was carried out, was located on two cement tennis courts. The courts were in close proximity (approximately 50 m) to the Department of Human Kinetics and Ergonomics, Rhodes University. All indoor testing was carried out in a thermo-neutral laboratory.

SUBJECTS

The sample consisted of 25 subjects; male provincial cricket academy and university cricketers were used. The minimum level competed at by all subjects was premier league, although several had already represented senior provincial A or B teams. The majority of players had some form of representative experience (junior or senior). The sample group included batsmen, bowlers, wicket keepers and all-rounders between the ages of 18 and 22 years.

SUBJECT RECRUITMENT FROM INSTITUTIONS

Initially the Border and Eastern Province cricket academies and Rhodes University cricketers were approached to establish whether they were willing to be involved. The

heads of the respective academy structures were contacted and informed of the purpose and nature of the study, while the University cricketers were contacted individually. A general outline of the requirements of the subjects was provided as well as the details of the data collection process. The respective administrators were assured that the institutions' and subjects' anonymity would be preserved and that subjects would be free to withdraw at any stage. They were also informed that feedback would be given to institutions and the subjects, if so desired. These institutions then informed the relevant individuals of the study. Those individuals from Rhodes University were included in the potential sample on a voluntary basis. Once individuals had volunteered, they were screened and included in the sample group.

SUBJECT SCREENING

Individuals were only included as subjects if they reported no evidence or history of recent illness. Prior to inclusion in the sample all prospective subjects completed a physical activity-screening questionnaire (Appendix A). This questionnaire showed that all subjects were in good health and free from risk of developing exercise-induced disorders.

MORPHOLOGICAL CONSIDERATIONS OF THE SAMPLE

Morphological variables such as body surface area (BSA) and percent body fat (% fat) have been shown to affect heat transfer between the body and environment (Wailgam and Paolone, 1984; Shephard, 1992), thus influencing human thermoregulation and tolerance to extreme environments. Shephard (1992) noted that heat exchange is proportional to BSA; body size influences thermoregulation by altering the ratio of heat producing tissue to surface area, which is further altered by cricket clothing and

protective batting coverings. The main influence of subcutaneous fat on thermal balance is that it insulates the body.

SUBJECT CHARACTERISTICS

Demographic data were collected on several occasions. The initial assessment was prior to participation in the study; additional measures were taken under each of the High and Low stress conditions. A summary of demographic data of the subjects collected on separate occasions is presented in Table IX. Relevant data of subject characteristics is presented in Figures 9a, b and c.

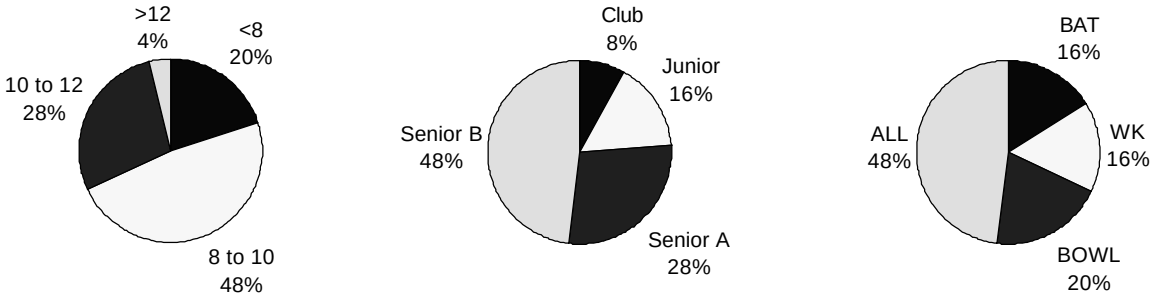
TABLE IX: **Demographic descriptions of the sample (n = 25): Means and SD.**

	High Stress	Low Stress
Age	19.0 ±1.1	-
Stature (mm)	1768 ±75	-
Mass (kg)	73.4 ±10.1	74.5 ±9.3
BMI (kg. $(m^2)^{-1}$)	23.4 ±1.9	23.7 ±1.6
RPI ($mm.\sqrt[3]{kg^{-1}}$)	423 ±11	421±9
BSA (m^2)	1.90 ±0.16	1.91 ±0.16
% Body Fat	13.0 ±2.8	11.9 ±3.5
LBM (kg)	64.3 ±8.6	65.4 ±7.6

(BMI – Body Mass Index; RPI – Reciprocal Ponderal Index; BSA – Body Surface Area; LBM – Lean Body Mass).

Mass, percent fat and lean body mass of the subject group was similar to the characteristics of South African national cricketers (Grey, 2001), 76.4 kg, 12.8 % and 66.5 kg respectively. However, the stature of national cricketers was greater. Stretch (1987) assessed South African first class cricketers and showed similar results for BSA (2.03 ± 0.10 m^2), RPI (417 ± 15 $mm.\sqrt[3]{kg^{-1}}$) and percent fat (9.3 ± 2.1%), although there were slight differences with stature (1808 ± 64 mm) and mass (81.7-83.6 kg) being

higher and percent fat (9.3 ± 2.1%) lower. In general the characteristics of the sample were similar to those of first class and international standard cricketers.



(a) (b) (c)

FIGURE 9a: **Number of years of cricket experience (% of subjects)**
9b: **Highest level of competition (% of subjects)**
9c: **Primary function of players (% of subjects)**

The cricketers were relatively young, the average age of the sample being 19 years, although 80% of the sample had played cricket for 8 years or more (Figure 9a). The minimum standard of play (Figure 9b) for any of the subjects included in the sample was first league cricket whilst 92% of players had some form of provincial representation (junior or senior level). Over 75% of the group had played senior provincial cricket, and almost 30% of the subjects had first class cricket experience. Even though not all subjects were first class cricketers, the sample is considered to be representative of a population that is of a high standard. Figure 9c indicates that there were an even number of batsmen and wicket keepers (16% each). All-rounders consider themselves players who both bat and bowl; they made up the largest number of subjects (48%). There were more bowlers (20%) than batters (16%).

ENVIRONMENTAL CHARACTERISTICS

The design of this study required subjects to perform cricket specific tests under two different environmental stress conditions. Within each High and Low environmental stress condition two clothing conditions were assessed, namely Full-Gear and No-Gear. Table X summarises the environmental conditions under which experimentation took place. It is evident from these data that significant differences existed between environmental conditions. Barring relative humidity, all environmental variables monitored under High stress were significantly greater ($P < 0.05$) than those collected during Low stress conditions.

TABLE X: **Summary of environmental variables measured under the different experimental conditions.**

		Ambient Temperature (T_A)	**Natural Wet Bulb Temperature (T_{NWB})**	**Globe Temperature (T_G)**	**Relative Humidity (RH)**	**Wet Bulb Globe Temperature (WBGT)**
H	**FG**	27.4 ± 2.9 **27.5**	19.3 ± 2.0 **19.5**	37.4 ± 3.9 **37.8**	46.3 ± 10.4 **47.0**	23.7 ± 2.2 **23.6**
	NG	27.6 ± 3.5 **27.0**	19.3 ± 2.0) **19.5**	37.9 ± 4.5 **38.8**	46.2 ± 11.9 **44.0**	23.9 ± 2.3 **23.5**
L	**FG**	16.0 ± 2.5 **16.0**	10.7 ± 1.8) **10.5**	21.5 ± 3.6 **22.0**	49.5 ± 14.2 **45.0**	13.4 ± 1.8 **13.6**
	NG	16.4 ± 2.7 **16.5**	10.6 ± 2.0) **10.0**	21.1 ± 3.5 **21.8**	48.4 ± 13.8 **46.0**	13.3 ± 2.1 **13.6**

Means ± SD, median for non parametric statistics in **bold**.

Under the High stress condition, mean heat stress was above 23 °C (WBGT) with T_A and RH above 27 °C and 46% respectively. According to the ACSM (1996) guidelines, these conditions constitute a high risk to the development of heat illness

in “runners”. The aforementioned position stand also shows that a WBGT of 18 to 23 °C constitutes a moderate risk, as a result 23 °C is the transition point between high and moderate risk zones. Therefore it is evident that some subjects would have been within the moderate risk area during assessments. As a result the High stress conditions were not considered to be severe. There is little information regarding what constitutes a thermal risk to cricket batsmen. It has been estimated (King and Christie, 2001) that cricket participation frequently occurs in environmental conditions that are far higher than those observed in the present study and players appear able to cope. As a result, environmental and playing conditions that constitute a risk, firstly of heat injury and secondly of performance decrement, still need to be established.

Under the Low environmental stress conditions the mean stress experienced was below 14 °C (WBGT), which would be considered a low thermal risk for runners. Therefore the Low stress environment is probably more akin to the conditions experienced in temperate playing spheres such as England, and for warmer climates would possibly reflect cooler periods, i.e. the start or end of a playing season.

Even though the differences between the High and the Low stress conditions were significant, it is clear that there was considerable variability within these test conditions. This variability is likely to contribute to variability within certain physiological responses, particularly those of skin temperature.

EXPERIMENTAL PROTOCOL

During the investigation, three testing sessions were completed by each of the subjects. The first testing session was used to screen volunteers, to explain the objectives of the research project, to provide information regarding test protocols and procedures, as well as obtain informed consent, habituate the subjects to the test procedure and to assign subjects to an experimental group. Demographic, morphological and reference data were collected in the laboratory. The objectives of the research project were presented in written form and verbally explained to the subjects (general information regarding testing is presented in Appendix A). The information was reiterated at the next two testing sessions.

All subjects read and signed the informed consent information sheet (Appendix A). The habituation process was carried out after morphological and baseline data had been recorded. The baseline physiological measure consisted of resting heart rate and was examined under "neutral" conditions in the laboratory. Subjects were familiarised with the reaction time test and the batting specific work-bout. Subjects were assigned to a subject test group (shown in Table XI) and were given a list of instructions to follow prior to their work-bout testing sessions (Appendix A).

The following two testing sessions occurred in the "field" and assessed subjects under different environmental (High and Low) and clothing (NG and FG) conditions. Each environmental condition was tested on a different day whilst both clothing conditions were performed during each of the High and Low environmental stress days. There were a total of four conditions and the subjects performed a work-bout during each session, with the order of clothing conditions randomised. Testing order for

environmental High and Low conditions could not be randomised, as these periods were dependent on season. High stress conditions were tested in the generally warmer "summer" season (October to February) and Low conditions in the cooler "winter" season (May to August) in order to maximise variance.

The initial aim was to test three subjects on each test day; however on various occasions only two were examined each day due to subject availability and factors beyond the control of the experimenter. On days when three subjects were tested investigations took place between 10h00 and 16h00. This period was shortened when subject pairs were assessed, although the lunch interval on these days was extended so that rest periods were similar. The testing periods for subjects and testing order are illustrated below, in Table XI.

TABLE XI**: Testing times and clothing condition order for environmental conditions.**

Time	**Low Stress Session**		**High Stress Session**	
	Subject Group	*Clothing Condition*	*Subject Group*	*Clothing Condition*
10h00	**A**	FG	**A**	FG
10h50	B	NG	B	NG
11h40	C	FG	C	FG
12h30	LUNCH	LUNCH	LUNCH	LUNCH
13h30	A	NG	A	NG
14h20	B	FG	B	FG
15h10	C	NG	C	NG
16h00	END	END	END	END

On their first test day subjects were randomly assigned to one of the subject groups A, B or C; where possible their test order and times were standardised between the two environmental test days to eliminate diurnal effects. Each work-bout (testing session) was approximately 24 min and the recovery period between work-bouts for a subject

was around 2 h 30 min (3 subjects) or 2 h (2 subjects). However, the total time taken to fit instrumentation, test the subject and remove instrumentation was about 50 min. The subject's recovery period started when the post-trial reaction test was complete, which was carried out immediately after the work-bout. The recovery period ended after lunch with the commencement of that particular subject's subsequent work-bout of that day. Since the recovery period between clothing conditions for each subject was over 120 min it is unlikely that there would have been carry over effects between trials.

Directions given to the subjects prior to each test session instructed them to arrive adequately hydrated (euhydrated); not to have consumed alcohol within the past 24 h; to have eaten sufficiently, but not within 3 h of being tested; not to have engaged in strenuous physical activity within 24 h of being tested and to inform researchers if ill.

At the start of each test day the subjects were weighed (underwear only) and the sites for skin temperature sensor placement were prepared and marked. Weighing occurred only after they had completed the test-day euhydration procedure. Site preparation involved shaving the area and cleaning with alcohol. Body composition estimates were then determined using BIA. Afterwards subjects were fitted with heart rate monitors, which were individually coded, and lay in a supine position for 3 to 5 min to get a baseline heart rate measure. Pre-exercise mass was recorded directly before fitting temperature sensors. The sensors and wires were secured and connected to the data logger. Subjects replaced clothes (cricket whites) and protective gear (when required), performed the choice reaction test and then proceeded to the field test area (tennis courts).

On arrival at the test area the time was noted and environmental conditions recorded. Subjects were encouraged to warm-up and stretch. The bowling machine was adjusted so that the subjects were comfortable with line and length of the delivery. These pre-test procedures took between 2 and 3 min to complete. When subjects were ready the speed sensor system was switched on, heart rate measurement was activated, anticipatory measures collected and the test started. The subjects then faced deliveries for a 7-Over period, sprinting two runs every third ball. RPE, thermal sensation and comfort ratings were collected on completion of the shuttle run at the end of each Over. Once the work-bout had been completed and environmental data collected, the subject walked from the testing area back to the laboratory, an approximate distance of 50 m. At the laboratory subjects performed the post-exercise batting specific reaction test, then the clothing ensemble and temperature sensors were removed so that the individuals could be weighed. The removed skin temperature sensors were wiped clean and dried for use on the second subject. Following the weighing procedure, the clothing ensemble was replaced. Note that during the weighing procedure, the heart rate monitor was not removed and remained attached throughout the test session in order to monitor recovery cardiac activity. Subjects then waited until their next testing condition. Recovery heart rate was continuously monitored for 40 min after the activity. Subjects were encouraged to change into dry clothing if available and were encouraged to consume fluid. During their recovery period, subjects not performing the test were utilised to operate the bowling machine and collect balls from the court, both physically undemanding activities.

The second subject (B) was weighed and fitted with instrumentation. The same pre-test procedures were observed before this subject walked to the field test area and was

allowed to start the trial. The work-bout and testing procedures observed for subject (A) were now repeated on subject (B); this format was continued until each subject had fulfilled both clothing conditions. After all three subjects had completed their first clothing trial they ate lunch, which consisted of a standard cold meal of approximately 2594 kJ (26.0 g protein, 17.3 g fat and 94.5 g carbohydrate). Subjects also consumed a 250 ml commercially available carbohydrate drink. Following lunch the subjects were tested during their second condition.

STATISTICAL ANALYSES

All statistical analyses were performed using the Statgraphics (Ver.6) software package. Basic descriptive statistics were conducted to accumulate general demographic and morphological data on the group. Descriptive measures of physiological, perceptual and performance data included means, standard deviations and medians. Tests of normality and homogeneity of variance showed that non-parametric statistics were appropriate.

EXPERIMENTAL DESIGN

The investigation involved the assessment of two main effects: environmental conditions (2 levels – High vs. Low) and clothing (2 levels – Full-Gear vs. No-Gear) on physiological, perceptual and performance responses of cricketers. The subject group, serving as its own control, was tested under each of the conditions within environment and clothing factors, which represents repeated measures. Therefore a two-factor ANOVA, repeated measures, was used to test the null hypotheses: (1) there were no differences between environmental treatments, (2): there were no differences between

clothing treatments. For each trial within environment and clothing factors, student t-tests were utilised to test differences between pre- and post-reaction time responses.

The experimental design resulted in four specific conditions: 1) High Full-Gear, 2) High No-Gear, 3) Low Full-Gear and 4) Low No-Gear. A one-way ANOVA was used to determine if there were differences in physiological, perceptual and performance responses between specific treatments. Tukey's post-hoc analyses were run to identify specific areas of differences. Several physiological and perceptual variables were measured throughout the batting activity, enabling the researcher to study the effect of batting duration on the various parameters examined. Student t-tests were utilised to determine whether there were differences between initial and final stages of batting for each specific condition. The same statistical procedures were used to investigate pre- and post-reaction time responses within the specific conditions. Chi-squared analyses were also used to ascertain differences between certain perceptual responses. For all comparisons a significance level $P \leq 0.05$ was considered significant.

CHAPTER IV

RESULTS AND DISCUSSION

INTRODUCTION

The purpose of this study was to determine the influence of protective cricket equipment and environmental conditions on physiological, perceptual and performance responses during batting activity.

Cricket is played in many regions, with players being subjected to varied and sometimes extreme environmental conditions. Within these environments batsmen rely on protective gear for the prevention of impact injuries. Their bulky equipment covers large portions of the body surface area, which may reduce heat dissipation and alter movement efficiency. It is possible that protective gear will influence both physiological and perceptual responses. This may ultimately exacerbate the impact of extremely hot and humid environments thereby adversely influencing components of the batting performance.

Batting trials were carried out under High (23.8 $\pm$ 2.2 °C) and Low (13.3 $\pm$ 1.9 °C) stress environmental conditions (WBGT). Within each environmental condition subjects performed the test wearing Full Protective Gear (FG) and No Protective Gear (NG). Thus four specific experimental conditions were investigated: High Full-Gear (HFG), High No-Gear (HNG), Low Full-Gear (LFG) and Low No-Gear (LNG).

The effects of environmental conditions, and clothing conditions on physiological, perceptual and performance parameters are examined separately. To assess the

influence of the environment during and after batting activity, results from the High-stress conditions were compared with those from the Low-stress conditions. Therefore both clothing conditions under High environmental stress conditions were pooled and compared to the combination of clothing conditions under Low environmental stress conditions.

Similarly, an evaluation of the impact of protective equipment compared all Full-Gear conditions with No-Gear conditions. As a result, High and Low-stress Full-Gear data were grouped and compared to the combination of High and Low-stress No-Gear responses.

Following these evaluations comparisons were made between the four specific conditions. The two environmental, two clothing and four specific conditions are examined in three separate sections of the discussion.

Throughout the discussion, various figures are used to demonstrate the responses to the batting trials. Where this discussion deals with the four specific conditions, most figures are coupled with post-hoc summary tables.

ENVIRONMENTAL CONDITIONS

PHYSIOLOGICAL RESPONSES

Several skin temperature responses were monitored over the entire exercise-bout, namely chest, forearm, shin and forehead. The averages* of these temperatures are

* Refers to the average of skin temperatures collected over the entire bout for each specific site: not to be confused with mean skin temperature, which is determined from the weighted average of several sites (chest, forearm, shin).

illustrated in Figure 10. The mean skin temperature (MST) was determined from the weighted average of chest, forearm and shin sites, and forehead temperature provided additional information regarding the local thermal state beneath the helmet.

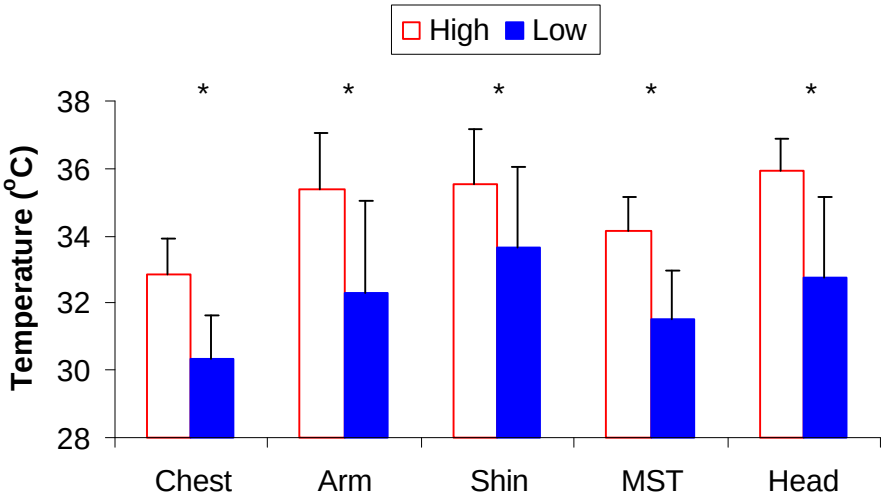


FIGURE 10: **Average skin temperature responses under High and Low environmental stress conditions.**

Note: In this, and all subsequent figures in this section of the results, * denotes significant difference between High and Low-stress conditions ($P < 0.05$) unless otherwise stated.

Figure 10 demonstrates that the environment significantly affected skin temperature responses. Average skin temperatures at all sites were significantly greater under High-stress than Low-stress conditions, producing MSTs of 34.14 ± 1.00 °C and 31.52 ± 1.44 °C for High and Low environmental stress conditions respectively. Similarly, average forehead temperatures were significantly higher under High (35.93 ± 0.93 °C) than Low (32.72 ± 2.41 °C) stress environments.

There was considerable variability between the temperatures at the various sites. Variability was evident under both environmental conditions; however, for skin temperatures greater variance was observed between and within sites under Low-

stress conditions. The coefficient of variation for sites under High-stress conditions ranged from 2.70 to 4.72 and under Low-stress conditions from 4.34 to 8.42. These findings are in agreement with Clark and Edohlm (1985) who reported that the local temperature of the skin varies considerably between different sites and the variations observed were greater under cooler conditions. The variability of the specific environmental factors within each environmental condition would have also contributed to the skin temperature variability. The WBGT coefficient of variability was greater for Low-stress conditions (13.4 to 15.8) than for High-stress conditions (9.2 to 9.6).

In comparison to typical MST of 33 °C reported by Parsons (1993), the batsmen exhibited values that were about 1 °C above this in the High-stress and 1.5 °C below in the Low-stress environment. The results demonstrate that MST was significantly greater under High-stress conditions. The findings confirm the results of earlier studies as summarised by Kerslake (1972), Åstrand and Rodahl (1977), and Clark and Edholm (1985) that MST is independent of the work rate, but dependent on the environment. Thus, irrespective of protective apparel, High-stress conditions place a greater thermal stress on batsmen.

Cardiac responses were also recorded throughout the activity and anticipatory heart rate was recorded just before the activity commenced. It is evident (Figure 11) that anticipatory heart rate responses were not influenced by the environmental conditions. Average heart rate was determined from measures taken throughout the work-bout, while peak heart rate was the highest value recorded during the bout. Both average and peak heart rate were significantly higher under High-stress, 138 ±

12 and 168 ± 10 bt.min^{-1} respectively, than under Low-stress conditions, 129 ± 11 and 162 ± 12 bt.min^{-1} respectively. It is apparent that even over a short duration (24 min) the High-stress condition placed a significant thermal stress on batsmen. This induces a significant increase in cardiovascular strain experienced by batsmen exercising at a similar intensity, with average heart rate 5% higher in the heat. This difference was independent of the clothing worn.

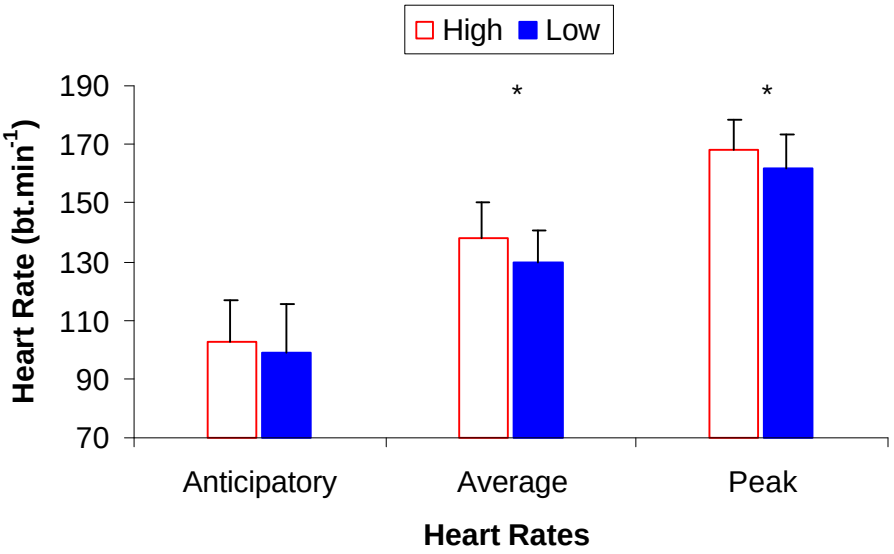


FIGURE 11: **Cardiac frequency responses under High and Low environmental stress conditions.**

It is common for hot and/or humid conditions to increase the environmental stress placed on the cardiovascular system (Moran **et al**., 1991). The observed cardiovascular limitations were probably due to an increase in skin blood flow that was likely to have occurred in order to facilitate cooling at the periphery. These and other associated circulatory responses are dealt with in more detail below.

Changes in body mass over the batting trials were recorded and from this, sweat losses (Figure 12) and sweat rates (Figure 13) were estimated. Sweat loss over the

bout, expressed in litres, was determined as an absolute value (L) and relativised for body mass (% BM). Sweat rates in litres per hour were likewise determined as absolute ($L.h^{-1}$) and relative values (% $BM.h^{-1}$). Again the ambient conditions exerted an unmistakable impact; all the sweat losses and sweat rates were significantly greater under High-stress conditions.

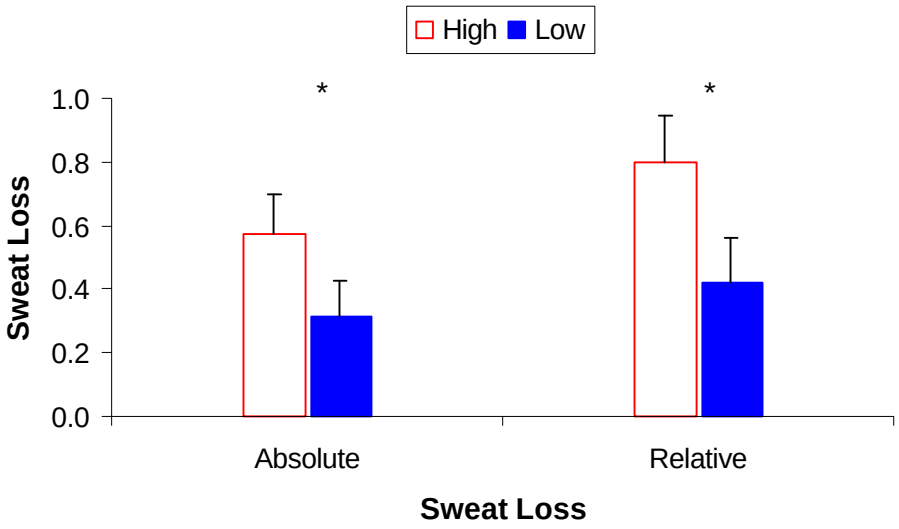


FIGURE 12: **Estimates of absolute (L) and relative sweat losses (% BM) during the cricket activity under High and Low environmental stress conditions.**

Given that mean environmental temperature was below mean skin temperature, any heat gained from the environment via physical processes was probably due to thermal radiation. However, it has been shown (Kato **et al**., 1997) that clothing, particularly if lightly coloured (Gonzalez, 1988), will assist in protecting the body from direct or reflected solar radiation. Consequently the primary factor responsible for additional sweat production probably reflects a disruption of dry heat loss mechanisms. As environmental temperature rises, under resting or working conditions, dry heat loss is known to decrease while vaporisation of sweat becomes more important (Gisolfi and Wenger, 1984; Sutton, 1996). To a lesser extent, given

the moderate ambient temperatures under the High-stress condition, radiant heat gained may also need to be lost. In conjunction with the elevations in skin temperature and heart rate, the increased sweat response provides further evidence of the physiological strain experienced as a result of increased thermal stress.

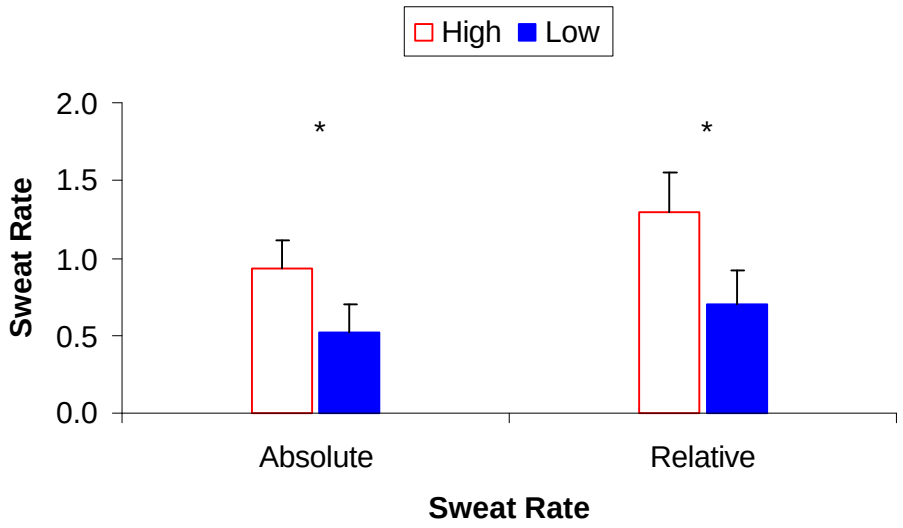


FIGURE 13: **Estimates of absolute (L.h^{-1}) and relative sweat rate (% BM.h^{-1}) for the work-bout under High and Low environmental stress conditions.**

Irrespective of the clothing worn, mean absolute sweat rate under the High-stress condition was 0.93 L.h^{-1} and 0.52 L.h^{-1} under Low-stress conditions. In the past (ACSM, 1975) and more recently (ACSM, 1996) it has been repeatedly advocated that athletes, in team sports or otherwise, replace exactly what is lost (Burke and Hawley, 1997). Therefore if players wish to restore what has theoretically been lost while batting during one-day matches in a moderate-to-hot environment, they should ensure that they consume nearly a litre of fluid for each hour of participation. However, batsmen only require half the amount when participating in cooler environments.

Gore **et al**. (1993) found that the sweat rate of batsmen under environmental conditions (22.1 to 26.4 °C WBGT) that were similar to the High-stress conditions of the current study, was 0.47 to 0.60 $L.h^{-1}$. The cohort used in their work averaged greater body masses and would have been expected to lose more fluid if exercising at a similar intensity because of higher metabolic rates (Dennis and Noakes, 1999). However, their work intensity was more representative of four- or five-day cricket, where work rates are more subdued, while the present study used a work-bout that is more similar to one-day batting intensities. It would appear then that players during one-day matches would lose more fluid as a result of the higher work rate. Fortunately, during one-day matches the total time spent batting is typically less than in first class matches, so the risk of significant dehydration is minimised. Even though dehydration is commonly cited as a problem in working or exercising situations (Åstrand and Rodahl, 1977; Sawka and Pandolf, 1990; Latzka and Montain, 1999), the importance ascribed to matching sweat loss and fluid intake has been questioned (Noakes, 2001).

PERCEPTUAL RESPONSES

Perceptual ratings were recorded at the end of each Over during the batting activity. The ratings of perceived exertion provided an overall indication of how demanding the activity was felt to be and represented the average value for the entire exercise-bout. The activity was perceived to be more demanding under High than under Low-stress conditions (Figure 14). Under High-stress conditions a perceptual rating of 13 (“somewhat hard”) was found to be significantly higher than under Low-stress conditions (rating 12). The physiological responses indicate that the strain

experienced is greater in the heat. Therefore it was expected that the activity would be perceived as being more demanding in a High-stress environment.

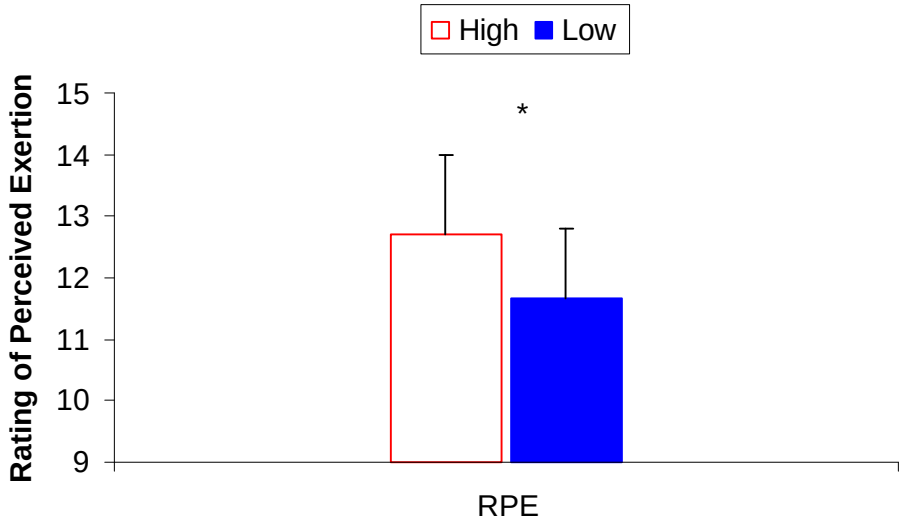


FIGURE 14: **Average rating of perceived exertion for the entire work-bout under High and Low environmental stress conditions.**

In addition to obtaining the subject's personal perception of the environmental conditions, thermal sensation ratings were also recorded after each Over. The average value for the 7-Over period is shown in Figure 15, while Figure 16 depicts a tally of all responses.

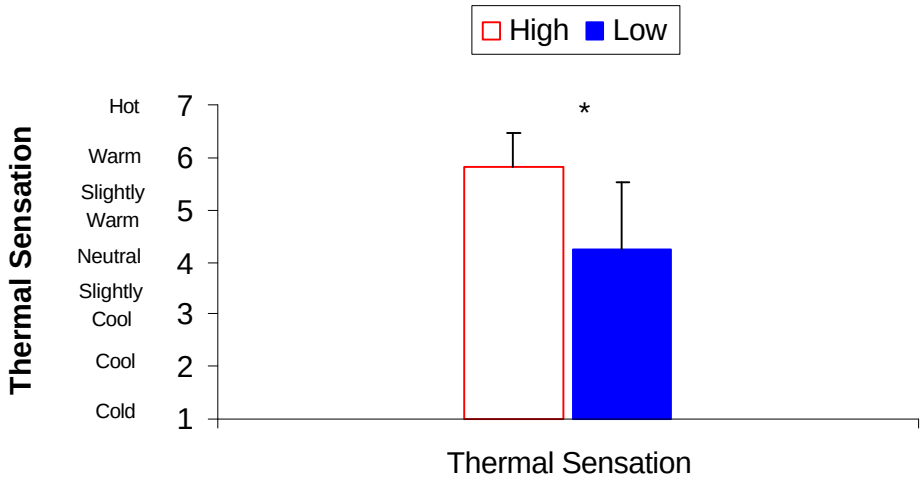


FIGURE 15: **Average thermal sensation ratings under High and Low environmental stress conditions.**

It is not surprising that both Figures 16 and 17 show responses under the High-stress condition to be significantly different from those of the Low condition. In the High conditions the average thermal sensation rating was nearly 6 (Warm), which is significantly greater than the sensation recorded under Low conditions (about 4; neutral). There were twice the number of ratings ranging from slightly warm to hot under High-stress (92%) than Low-stress conditions (46%).

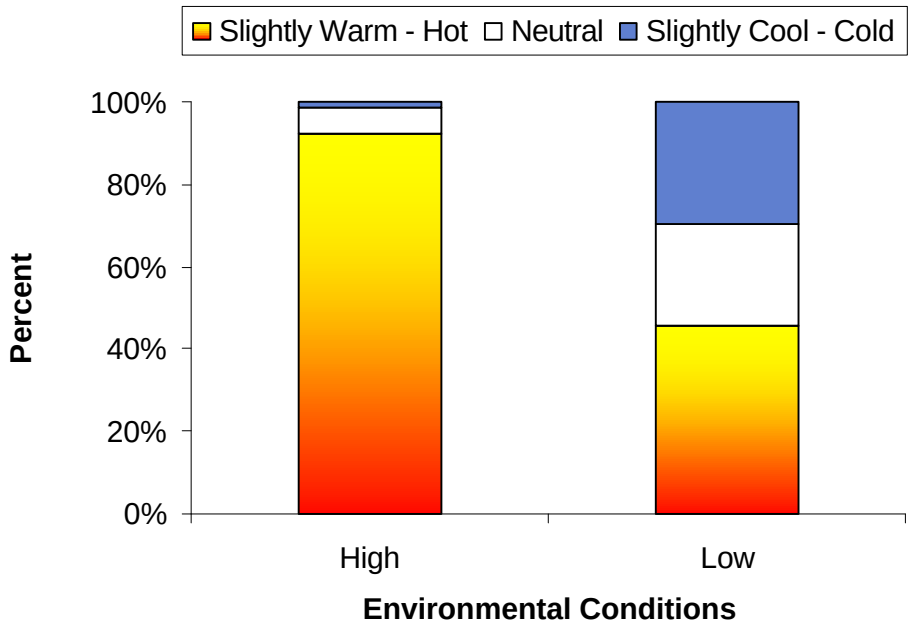


FIGURE 16: **Incidence (%) of thermal sensation ratings under High and Low environmental stress conditions.**

PERFORMANCE RESPONSES

Monitoring sprint times during the work-bout and examining pre- and post-activity batting specific reaction times gave an indication of certain factors related to cricket performance under different environmental conditions. The environment appears to affect some, but not all performance responses. Fourteen sprint sets were carried out

in each bout. Since sprint times for all sets were no different, the average of these is represented in Table XII as means of fractionated sprint times. The OVERALL time taken to sprint to the opposite crease and back was 5.89 ± 0.20 s under Low and 5.76 ± 0.22 s under High-stress conditions. It appears as though the first sprint (SPRINT 1) and OVERALL sprint times were significantly slower under the Low-stress than under the High-stress condition. No difference was observed between the two environmental conditions for turn times or for the second sprint time. Assuming the mean overall sprint time for both conditions was 5.8 s and accounting for the placement of the infra-red sensors, the distance covered each sprint set (30.1 m) resulted in an average speed of 5.2 $m.s^{-1}$ (18.7 $km.h^{-1}$).

TABLE XII: **Mean fractionated sprint times during the work-bout under High and Low environmental stress conditions.**

	Fractionated Sprint Times (s)			
	SPRINT 1	**SPRINT 2**	**TURN**	**OVERALL**
High	2.34 ± 0.09 **2.34**	2.33 ± 0.111 **2.35**	1.09 ± 0.09 **1.10**	5.76 ± 0.20 **5.75**
Low	2.40 ± 0.09 **2.40**	2.36 ± 0.107 **2.38**	1.11 ± 0.10 **1.10**	5.86 ± 0.22 **5.87**
P-value	(P < 0.001)*	(P = 0.078)	(P = 0.555)	(P = 0.007)*

Means ± SD, median for non-parametric statistics in **bold**.

Physiological responses indicate that the thermal stress was greater under High environmental stress than under Low-stress conditions. Current beliefs often associate a greater thermal stress with an adverse effect on performance. However, the above sprint times are somewhat paradoxical since the sprint times are actually faster when thermal stress is elevated. It is plausible that a warm-up effect accounted for improved running performance in hotter conditions. The High-stress conditions

facilitated the process of loosening joints and lowering muscle viscosity and the cooler conditions impeded this process. Increases in body temperature will increase the rate of chemical reactions within the body, therefore the rate at which physical and mental tasks are carried out may increase under conditions of thermal stress (Poulton, 1976). There is a clear indication that hot conditions do not adversely affect sprint performances during short duration batting activity.

Batting specific reaction times are presented in Figure 17. Comparisons were drawn between environmental conditions and within conditions between pre- and post-reaction times. Under High-stress conditions, pre- (0.58 ± 0.06 s) and post- (0.58 ± 0.06 s) choice reaction times were no different than under Low-stress conditions, 0.57 ± 0.08 s and 0.56 ± 0.07 s respectively. It is interesting that the reaction times appeared faster after the activity than before, although this difference was only significant under Low-stress conditions. This may have been due to the effect of players “warming-up” during the activity and achieving an increased state of arousal. The bout was only 24 min in duration and although the work rate was high intensity, it was probably not of sufficient duration to cause undue fatigue. Thus the combined stress of the environment and activity appeared to result in an improvement in choice reaction times instead of a deterioration. In essence the exercise probably improved muscle function by providing an adequate warm-up. The implication for cricket performance is that in order to enhance reaction time and possibly performance, players should employ an adequate warm-up. It appears as though there is greater necessity to warm-up in cooler environments.

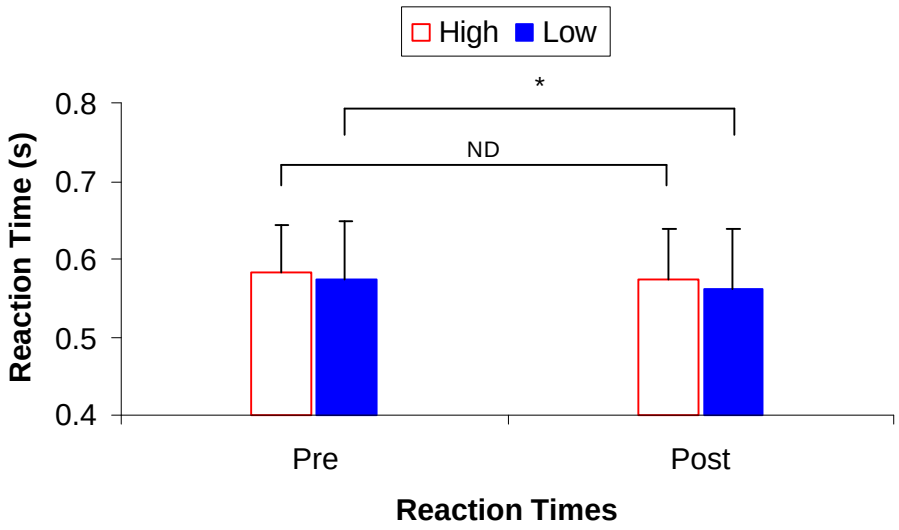


FIGURE 17: **Pre- and post-activity choice reaction times under High and Low environmental stress conditions.**

Note: * denotes a significant difference between pre- and post-work-bout reaction times under Low-stress conditions ($p < 0.05$), ND denotes no difference.

The responses indicate an increased thermal stress and associated physiological strain on the subject group yet it appears as though this stress over a short duration actually enhanced performance instead of hindering it. It is possible that if the same intensity activity was performed in a similar environment for an extended period of time then there may be a gradual deterioration of the physiological system and eventual hindrance to performance. This is speculative; further investigation is required to determine at which point in time deterioration in performance might occur. However, the present data suggest that for a batting interval of 24 min, the thermal stress experienced under these environmental conditions and at this rate is actually beneficial to performance. The implication for one-day performance is that players batting for short periods in ambient conditions of 23.8 °C (WBGT) or lower are unlikely to experience any deterioration in performance due to environmental stress.

CLOTHING CONDITIONS

PHYSIOLOGICAL RESPONSES

Protective batting apparel significantly influenced the average skin temperature responses (Figure 18). It is clear that sites where protective clothing was placed directly over the skin (forearm, shin and forehead) registered significantly greater temperatures. Only the chest site, which had no protective covering for either of the clothing conditions, showed no difference between clothing conditions. The overall effect of the increased skin temperatures brought about an increase in the MST under Full-Gear conditions.

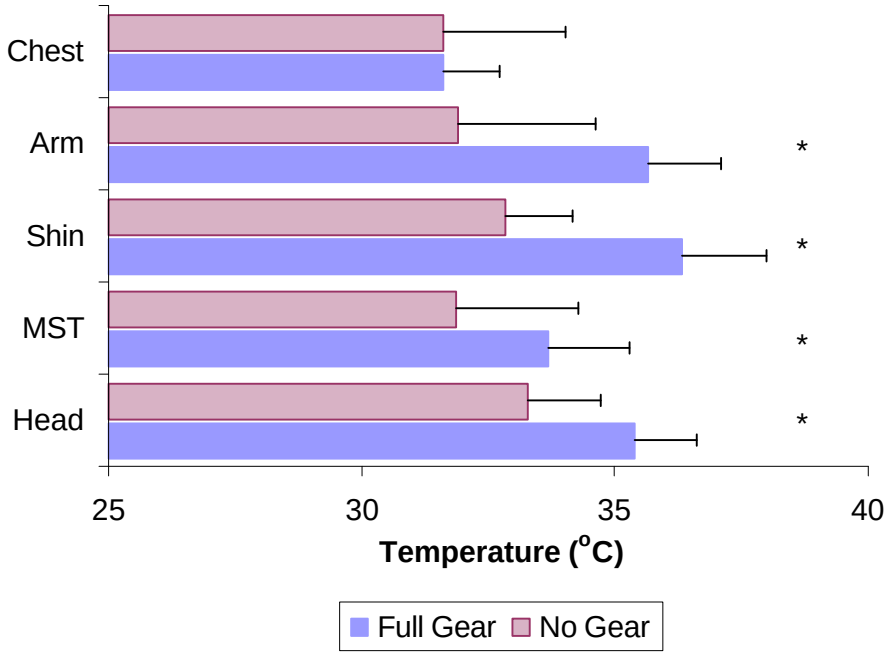


FIGURE 18: **Average skin temperature responses under FG and NG clothing conditions.**

Note: In this, and subsequent figures in this section of the results * denotes significant difference between FG and NG clothing conditions ($P < 0.05$), unless otherwise stated.

It is evident then that the use of a protective batting ensemble significantly elevates skin temperatures. Irrespective of environmental conditions, the MST and forehead

temperature under Full-Gear conditions were 33.69 ± 1.24 °C and 35.38 ± 1.60 °C respectively, while under No-Gear conditions MST and forehead temperatures were 31.86 ± 1.84 °C and 33.28 ± 2.68 °C respectively. Under Full-Gear conditions MST was similar to normal MST (33 °C), however under No-Gear conditions the temperature was lower than typical temperature.

Anticipatory, average and peak cardiac responses are depicted in Figure 19. As with environmental conditions, there was no difference in anticipatory heart rate responses between either of the clothing conditions. However, average 136 ± 13 and peak 166 ± 12 bt.min^{-1} heart rates were significantly higher when wearing Full-Gear than under No-Gear conditions, 132 ± 12 and 164 ± 11 bt.min^{-1} respectively. In terms of average heart rate this response represents an increase of 3%.

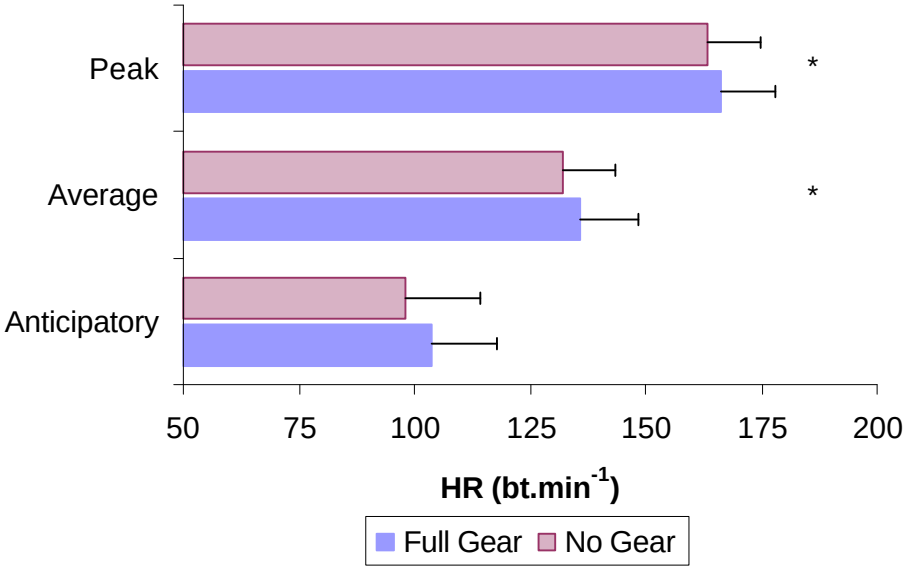


FIGURE 19: **Cardiac frequency responses under FG and NG clothing conditions.**

These elevated cardiac responses indicate that there was an additional stress placed on the cricketers when wearing protective clothing. The increase in the heart rate

response is more than likely due to an elevated thermal load, decrease in movement efficiency and additional load carried as a result of the protective outfit (Pascoe **et al**., 1994b; Ftaiti **et al**., 2001). The extent to which each of these factors contributes to the elevated heart rate is difficult to determine from these data.

Estimated fluid losses and sweat rates are shown in Figures 20 and 21 respectively. All fluid loss and sweat rate parameters were significantly higher when subjects wore Full batting Gear. Protective garments were shown to increase skin temperatures and probably the thermal load. Under Full-Gear conditions the elevated skin temperatures most likely signify a combination of an increase in warm blood flow to the skin in an attempt to aid cooling and the protective garments disrupting heat loss from the periphery. Ultimately the body will be required to produce greater quantities of sweat to enhance evaporative cooling and maintain thermal homeostasis. The increased sweat production implies an elevation in thermal stress under Full-Gear conditions.

The rate of sweat loss, irrespective of environmental conditions, whilst wearing Full-Gear was 0.78 $L.h^{-1}$, vs. 0.67 $L.h^{-1}$ for No-Gear. Exercising in higher environmental temperatures but at lower work rates, Gore **et al**. (1993) observed lower sweat rates than No-Gear conditions of the current investigation. This emphasises the significance exercise intensity plays in determining the rate of fluid loss. Batsmen need to be aware that they are likely to lose more fluid in one-day matches than first class matches, provided they bat for a similar duration. A sweat rate 0.78 $L.h^{-1}$ is, in comparison to other team sports, not considered excessive (Burke and Hawley, 1997) and should be relatively easy to replace during cricket participation. However,

an innings in a one-day match is typically over 3 hours, so some players may spend an extended period batting. If players do not rehydrate adequately during and between the innings they run the risk of starting the fielding session significantly dehydrated. Similarly, when fielding first, players such as all-rounders may become slightly hypohydrated and may then further dehydrate when batting.

FIGURE 20: **Estimated absolute (L) and relative (% BM) sweat losses under FG and NG clothing conditions.**

FIGURE 21: **Estimates of absolute (L.h^{-1}) and relative (% BM.h^{-1}) sweat rate under FG and NG clothing conditions.**

PERCEPTUAL RESPONSES

The perceptual responses are shown in Figure 22. There was no difference in perceived exertion responses (rating of 12, “fairly light – somewhat hard”) between Full-Gear and No-Gear conditions. The results clearly indicate that protective gear influenced physiological responses and significantly altered the responses of nearly all variables examined. It is surprising, therefore, that the cricketers did not perceive the activity to be more demanding while wearing protective apparel. It appears that even though modern protective clothing places a greater load on physiological processes compared to No-Gear, this load is not perceived to be significantly different. This may be attributed to a familiarity and acceptability of the protective equipment.

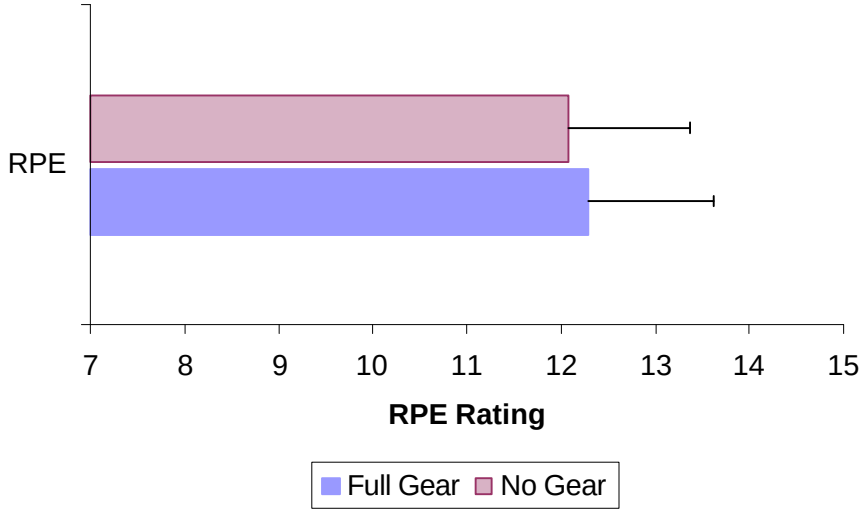


FIGURE 22: **Average rating of perceived exertion under FG and NG clothing conditions.**

For average thermal sensation ratings (shown in Figure 23), no difference was observed between clothing conditions. The rating was 5 (“slightly-warm”). The thermal sensation tally (Figure 24) indicated that the incidence of ratings ranging from slightly warm to hot was similar, 71% and 67% under Full-Gear and No-Gear conditions respectively.

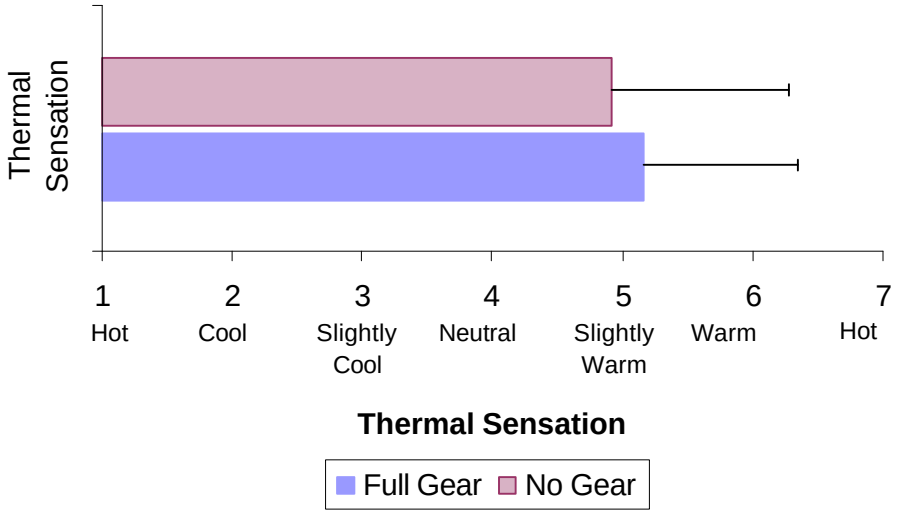


FIGURE 23: **Average thermal sensation ratings under FG and NG clothing conditions.**

The stress placed on cricketers as a result of protective clothing was evident from increased physiological strain experienced. Nevertheless, additional gear did not appear to influence either of the perceptual variables: perceived exertion or thermal sensation. Thus ambient conditions are suggested to be a more important predictor of perceptual strain than the protective clothing.

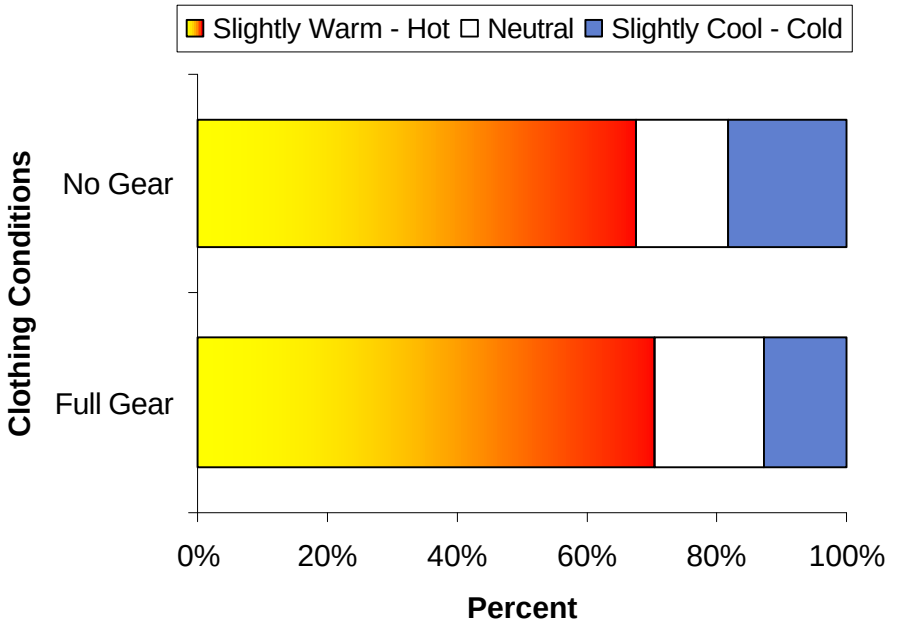


FIGURE 24: **Incidence (%) of thermal sensation ratings under FG and NG clothing conditions.**

PERFORMANCE RESPONSES

Mean fractionated sprint times (Table XIII) were significantly slower when players wore Full batting Gear. With the exception of the TURN time, all sprint measures were slower. The overall sprint time under Full-Gear conditions was 5.89 ± 0.20 s and under No-Gear conditions was 5.73 ± 0.20 s.

TABLE XIII: **Mean fractionated sprint times under FG and NG clothing conditions.**

	Fractionated Sprint Times (s)			
	SPRINT 1	**SPRINT 2**	**TURN**	**OVERALL**
Full Gear	2.40 ±0.09 **2.42**	2.39 ±0.10 **2.39**	1.10 ±0.09 **1.10**	5.89 ±0.20 **5.92**
No Gear	2.33 ±0.08 **2.33**	2.30 ±0.10 **2.32**	1.10 ±0.10 **1.10**	5.73 ±0.20 **5.76**
P-value	(P < 0.001)*	(P < 0.001)*	(P = 0.376)	(P < 0.001)*

Means ± SD, median for non-parametric statistics in **bold**.

Slower sprint times were probably due to a disruption of mechanical or movement efficiency as a result of the bulkiness and frictional characteristics of the protective kit. It is possible that the additional weight may have contributed to slower running speed although the additional load carried was only about 9.3 kg. Thus the increased load of the gear and the disruption to mechanical efficiency were probably the factors responsible for the slower sprint times under Full-Gear conditions.

Pre- or post-activity choice reaction times (Figure 25) were no different between Full-Gear and No-Gear conditions, although under Full-Gear conditions pre-activity reaction times (0.58 ± 0.07 s) were significantly slower than post-activity times (0.57 ± 0.07 s). Under No-Gear conditions pre-trials were no different to post-trials. Again

the effects of warm-up and increased arousal were probably responsible for improved post-activity reaction times for Full-Gear conditions.

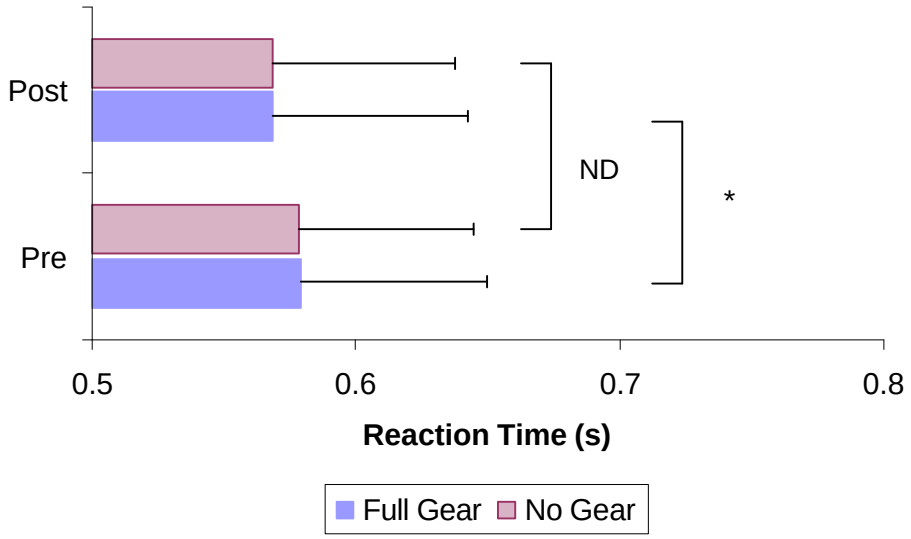


FIGURE 25: **Pre- and post-activity choice reaction times under FG and NG conditions.**

Note: * denotes a significant difference between pre- and post-activity reaction times under Full-Gear conditions ($p < 0.05$), ND denotes no difference.

COMPARISON OF SPECIFIC CONDITIONS

During cricket matches batting activity never occurs without protective equipment, but the pooled data utilised in the two-way analyses do not identify the exact demands of actual match conditions. This section of the discussion investigates differences between the four specific experimental conditions. One-way analysis of variance was utilised to compare High-stress Full-Gear (HFG), High-stress No-Gear (HNG), Low-stress Full-Gear (LFG) and Low-stress No-Gear (LNG) trials. The relevance of one-way analysis of specific conditions is that it provides a control condition with which to compare specific match conditions. Based on the hypotheses set out, the condition that imposed the least demand was the Low-stress No-Gear condition. This control was

utilised to determine to what extent the effects of clothing or environment were more pronounced under exact batting conditions. Therefore, the primary concern was the differences between High and Low (HFG vs. LFG and HNG vs. LNG) conditions, the differences between Full and No-Gear (HFG vs. HNG and LFG vs. LNG) conditions, and evaluating whether environment or clothing had a greater impact (HNG vs. LFG). Comparisons of HFG vs. LNG were of least interest in the investigation.

PHYSIOLOGICAL RESPONSES

Skin Temperature Responses

Average skin temperature responses are summarised in Table XIV and the post-hoc summary (Table XV) indicates where significant differences existed between specific conditions. All areas where Protective Gear was worn showed significantly higher skin temperatures compared to when No Protective Gear was used. As expected, this trend was reproduced for MST. The data clearly indicate that the protective ensemble raises skin temperatures during cricket activity. Chest temperature responses highlight this in view of the fact that this site was covered by only clothing and had no protective cover for either of the clothing conditions. Consequently no differences were revealed between FG and NG conditions within either High or Low-stress environments. There were, however, differences in chest temperature between High and Low environments. At every site, except the chest, the HFG condition resulted in significantly higher temperatures than any other condition. Under LFG conditions the skin temperature at any site, again with exception to chest, was always higher than under LNG conditions. At the forearm and shin, protective gear raised the skin temperature of the LFG condition above that of HNG, although this was only significant at the shin.

TABLE XIV: **Summary of overall average skin temperature responses under specific conditions.**

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	Skin Temperatures (°C)				
	Arm	**Shin**	**Chest**	**MST**	**Forehead**
HFG	36.73 ±0.94 **36.84**	36.93 ±0.60 **37.01**	32.83 ±1.06 **33.12**	34.83 ±0.64 **34.98**	36.47 ±0.56 **36.58**
HNG	34.05 ±1.04 **34.13**	34.16 ±1.03 **34.53**	32.92 ±1.10 **32.87**	33.49 ±0.83 **33.39**	35.40 ±1.00 **35.27**
LFG	34.74 ±1.14 **34.85**	35.71 ±1.20 **36.17**	30.36 ±1.20 **30.43**	32.68 ±0.60 **32.74**	34.29 ±1.55 **34.47**
LNG	29.92 ±1.33 **30.14**	31.53 ±1.10 **31.44**	30.32 ±1.45 **30.57**	30.36 ±1.03 **30.49**	31.16 ±2.09 **31.22**

Means ± SD, median for non-parametric statistics in **bold**.

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear, LNG = Low No-Gear.

The combination of the chest, forearm and shin skin temperatures produced MST under High-stress conditions of 34.83 °C and 33.49 °C for HFG and HNG respectively. In Low-stress environments FG (32.68 °C) was greater than NG (30.36 °C). The differences between the FG and NG within High or Low conditions were significant. Mean skin temperature under HNG and LFG conditions were similar to normal MST of 33 °C (Parsons, 1993) although in High-stress environments protective clothing raised the skin temperature almost 2 °C above this typical level, while under Low-stress the NG condition was nearly 3 °C below typical MST.

The results support the findings of Davies (1979) that under higher environmental loads, namely ambient temperature, skin temperatures are higher. In addition, protective gear is known to hinder heat loss (Cheung **et al**., 2000), and Mathews **et al**. (1969) found protective clothing to impede heat loss from the skin thereby

significantly elevating temperatures compared to conditions where no padding was used. The present study is in agreement with these findings.

TABLE XV: **Post-hoc summary of average skin temperature responses, indicating differences between specific conditions.**

		HFG	HNG	LFG	LNG
Chest	HFG	-	ND	§	§
	HNG		-	§	§
	LFG			-	ND
	LNG				-
Forearm	HFG	-	§	§	§
	HNG		-	ND	§
	LFG			-	§
	LNG				-
Shin	HFG	-	§	§	§
	HNG		-	§	§
	LFG			-	§
	LNG				-
MST	HFG	-	§	§	§
	HNG		-	§	§
	LFG			-	§
	LNG				-
Forehead	HFG	-	§	§	§
	HNG		-	§	§
	LFG			-	§
	LNG				-

Note: In this, and subsequent post-hoc tables in this section of the results, § denotes a significant difference between specific conditions ($P < 0.05$), ND denotes no difference.

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear; LNG = Low No-Gear.

The average MST responses suggest that High environmental stress places a greater burden on batsmen than protective equipment. Protective gear exacerbates the impact of the environment. The result is that the HFG condition induces the greatest skin temperatures and therefore thermoregulatory strain. Higher skin temperature lowers the threshold level for sweating (Wenger **et al**., 1975). Therefore it is expected that the highest sweat rates will occur under the HFG condition.

Chest, Forearm and Shin Temperature vs. Overs

The alterations to chest temperature over the batting period are demonstrated in Figure 26 while the differences between the conditions are revealed in the post-hoc analysis (Table XVI). Full-Gear and No-Gear responses were identical under the High conditions with an insignificant variation over the entire exercise duration. Under Low-stress conditions chest temperature responses for both clothing conditions also followed a near identical trend. However, these temperatures dropped consistently throughout the activity, the first and last Over differing significantly. At the start of activity there was a significant difference in chest temperature between the High and Low conditions. As the activity progressed the decreasing skin temperatures under Low-stress conditions enlarged the disparity between High and Low environmental conditions. It was evident that the trends observed were entirely dependent on the thermal stress imposed by the environment.

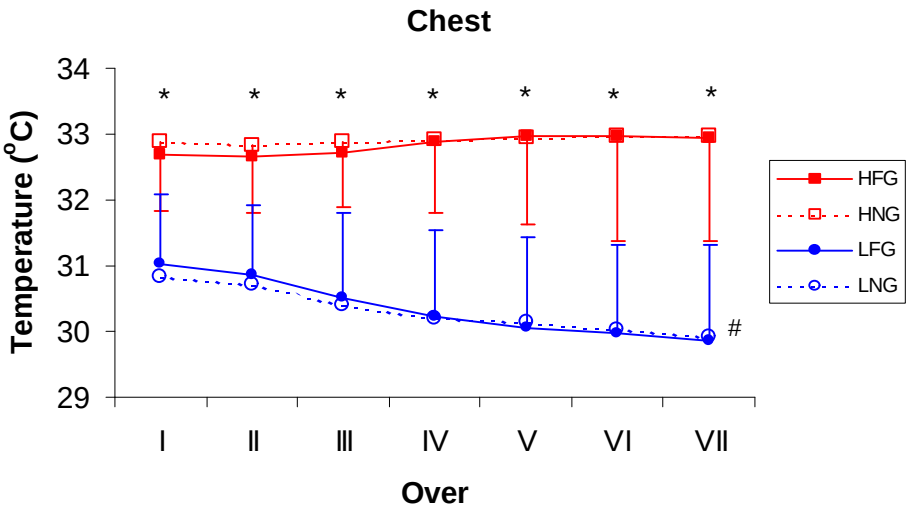

FIGURE 26: **Mean chest temperatures for each Over during the batting work-bout.**

Note: Post-hoc analysis, Table XVI indicates significant differences (*) between specific conditions.
# denotes significant difference between initial and last Over ($P < 0.05$).

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear; LNG = Low No-Gear.

Forearm temperature changes are depicted in Figure 27. With the exceptions of HNG and LFG conditions during the initial three Overs, there were significant differences (Table XVI) between all conditions over the entire exercise duration. Full-Gear conditions in High and Low environments were significantly different throughout and the trends followed were almost identical. Both temperatures rose consistently from the start of activity; this rate of increase gradually subsided and appeared to reach a plateau towards the end of the bout. No-Gear conditions were also significantly different, with those skin temperatures under High-stress conditions significantly greater than under Low-stress environments. The NG conditions also follow a consistent trend and remain relatively unchanged over the bout.

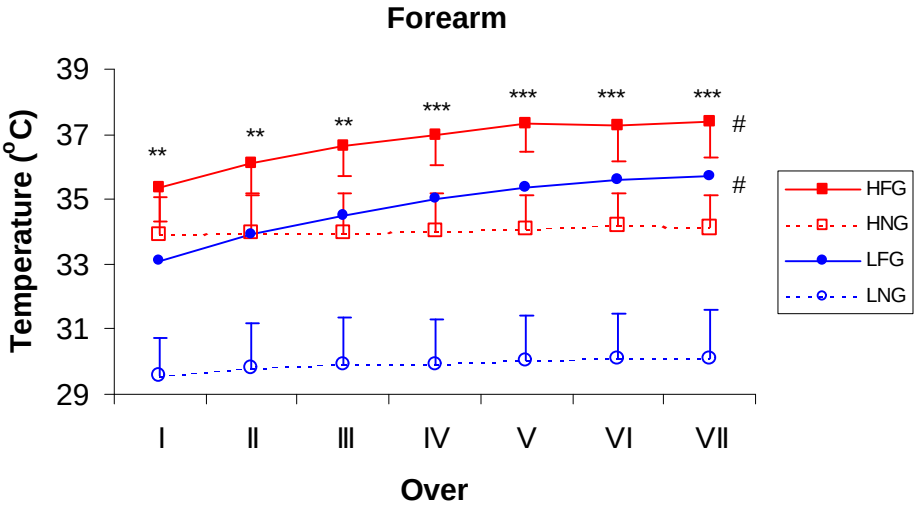

FIGURE 27: **Mean forearm temperatures for each Over during the batting work-bout.**

Note: Post-hoc analysis, Table XVI indicates significant differences (** and ***) between specific conditions.
# denotes significant difference between initial and last Over ($P < 0.05$).

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear; LNG = Low No-Gear.

The trends for shin temperature responses over the work-bout (Figure 28) closely replicated forearm temperature trends. Both FG conditions were significantly different

(Table XVI), followed the same pattern and increased almost in parallel to one another until the end of the bout, although it does not appear as though equilibrium was reached for the FG conditions. Temperatures under NG conditions were also significantly different between environmental conditions yet remain relatively unchanged over time. At the start of the bout, under High-stress conditions, skin temperatures are about 2 °C higher when covered by padding than when not covered. Under Low-stress conditions this difference is nearly 3 °C. As batting progressed these differences between FG and NG were accentuated. Shin temperature increased significantly between first and last Over for FG conditions (High and Low). Full-Gear or No-Gear conditions were greater when the environmental stress was greater.

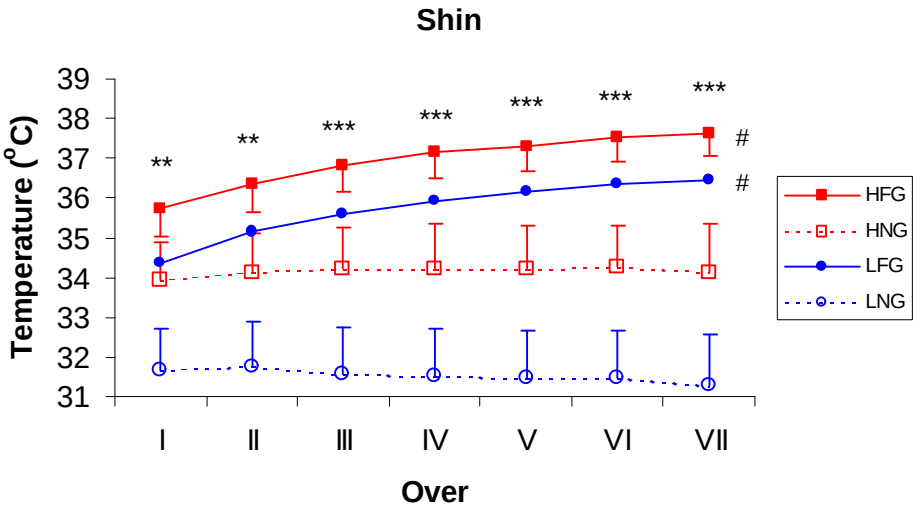

FIGURE 28: **Mean shin temperatures for each Over during the batting work-bout.**

Note: Post-hoc analysis, Table XVI indicates significant differences (** and ***) between specific conditions.
# denotes significant difference between initial and last Over ($P < 0.05$).

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear; LNG = Low No-Gear.

TABLE XVI: **Post-hoc summary of chest, forearm and shin temperature responses each Over, indicating differences between specific conditions.**

	Chest				Forearm and Shin[1]							
Over	**I to VII***				**I to III****				**IV to VII*****			
	HFG	HNG	LFG	LNG	HFG	HNG	LFG	LNG	HFG	HNG	LFG	LNG
HFG	-	ND	§	§	-	§	§	§	-	§	§	§
HNG		-	§	§		-	ND	§		-	§	§
LFG			-	ND			-	§			-	§
LNG				-				-				-

Note: Asterisks code as in Figures 26 to 28 above.
[1] The sole exception was a finding of significant difference between HNG and LFG in shin temperatures for Over III.

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear; LNG = Low No-Gear.

It is clear that padding resulted in forearm and shin temperatures that were significantly higher than when No-Gear was used. In addition, no padding resulted in relatively unchanged responses, while padding brought about consistent increases in skin temperature over the batting period. These elevations were significantly higher at the end of the bout than compared to the start.

Both forearm and shin temperature responses indicate that LFG conditions are greater that HNG conditions. Therefore the greatest thermal stress is a result of protective layers, with the environmental load further elevating this stress. These findings agree with average skin temperature responses for the forearm and shin, but conflicts with average MST responses.

Padded and Unpadded Sites

It has already been shown that the responses support the well-established position that skin temperature is dependent on ambient temperature, but independent of work rate. However, there are changes in the skin temperature responses that cannot be explained by environmental factors alone. From the results, it would seem reasonable to surmise that the responses were dependent on environment and exacerbated by clothing. Closer investigation of the variation in temperature trends between the sites indicates that the relationship is not as straightforward as stated.

It was revealed earlier that batting in a protective outfit resulted in skin temperatures being significantly different between FG and NG conditions, although the pattern observed at the forearm and shin was not reproduced at the chest. Protective equipment was certainly responsible for differences at forearm and shin; however, noting those areas that were actually covered by padding better elucidates the trends. At the start of exercise there were already differences in skin temperature. Naturally for uncovered areas this discrepancy in temperature was entirely dependent on the environment. Differences between covered areas were not as pronounced as uncovered regions, but were also influenced by the environment. Skin temperature adjustments over the bout (Table XVII) indicated that, irrespective of clothing conditions, when sites were directly exposed to the environment (forearm) or covered by only clothing (chest and shin), temperatures remained relatively stable or decreased slightly. In these situations skin temperatures under cooler conditions tended to drop or remain unchanged, while under the warmer conditions, were relatively unchanged. Irrespective of environment those sites that were directly

covered by padding (shin and forearm) showed a uniform trend with increases in skin temperature responses throughout the activity.

TABLE XVII: **Outline of how sites responded to being covered directly with padding compared to those areas that were not covered.**

Exposure to Environment	Environmental Stress	Temperature Adjustments
Uncovered	High Low	Unchanged Decreased or unchanged
Covered	High Low	Increased Increased

Protective equipment such as cricket padding increases thermal insulation, prevents vapour transfer to the environment and limits airflow across the skin, factors which Pascoe **et al**. (1994a) and Cheung **et al**. (2000) have identified as disturbing the physical mechanisms of heat transfer. The barrier creates a humid microclimate beneath the apparel, thereby disrupting evaporative cooling, while the inability of convective currents to penetrate the gear or move across the skin surface creates an insulative layer beneath the padding, resulting in reductions in dry and evaporative heat loss. This explains why, even under Low-stress conditions, covered sites showed no respite in respect of the skin temperature gains.

In the absence of a barrier, dry and evaporative processes are relatively unhindered. Under cool conditions, the uncovered or directly exposed skin will easily lose heat to the environment, with the convective cooling processes being further enhanced by running, or body movement, and wind, thus explaining the consistent decrease in skin temperatures under cool conditions. However, under High-stress conditions environmental temperatures were more severe, so dry heat loss processes would be

less efficient (Nielsen, 1938) and evaporation of sweat would be required to maintain the consistent skin temperatures.

Mean Skin and Forehead Temperature

The MST responses over the duration of the 7-Over work-bout are shown in Figure 29, with post-hoc analysis indicated in Table XVIII. Under High-stress conditions while wearing NG it is evident that MST was relatively stable (ranging from 33.4 °C to 33.6 °C) and did not increase significantly over the duration of the activity. In contrast, the MST responses were significantly higher when wearing FG as opposed to NG and increased significantly from the first to the last Over. The increase in MST under the HFG temperature reached a plateau at about the 6th Over. Differences between HFG and HNG can be attributed to protective gear since the work rates were consistent and environmental conditions equivalent. The trends observed for MST are similar to those of King **et al**. (2002), who examined cricketers under environmental conditions of more than 23 °C (WBGT).

Under Low-stress conditions there were also differences between clothing conditions. No-Gear conditions resulted in the MST decreasing slightly from start to end, while protective equipment brought about a small, but significant increase over the same period. Clothing clearly increases the thermal load placed on an individual, but under Low conditions this increase may be favourable by improving comfort. It was also evident that the environment had a significant impact on MST, with all responses under High conditions being significantly higher than those under Low environmental stress. Since the work rate was consistent for all trials, these findings again support the notion that MST is independent of work rate, but dependent on environment.

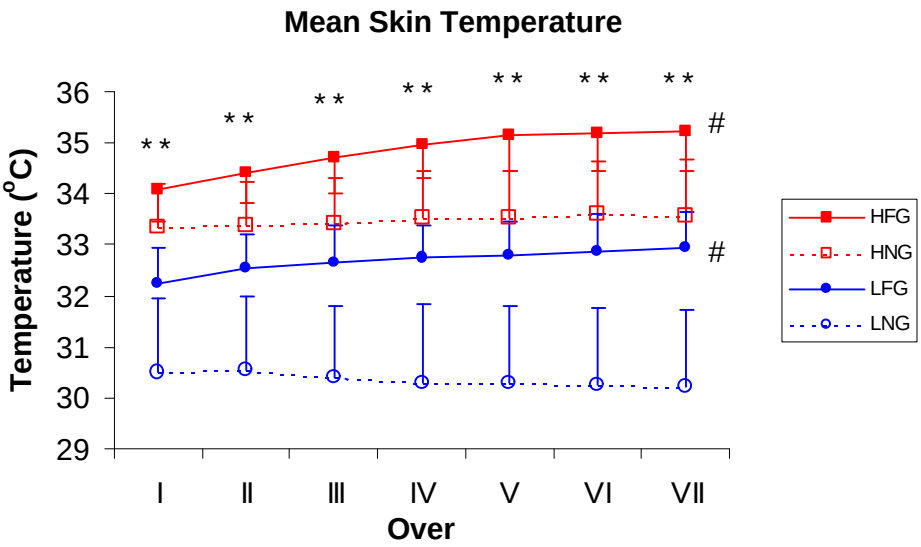

FIGURE 29: **Mean skin temperature for each Over during the batting work-bout.**

Note: Post-hoc analysis, Table XVIII indicates significant differences (**) between specific conditions.
# denotes significant difference between initial and last Over ($P < 0.05$).

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear; LNG = Low No-Gear.

Thermal strain is greatest under HFG conditions. Comparing changes in MST to those of the shin and forearm, the increases in temperature were more gradual for MST over the bout. Chest temperature is responsible, since in determining MST the chest site is weighted heavily as it is representative of a large surface (chest and back) area. The extremities constitute 65% of the body's total surface area and have been identified as playing a major role in thermoregulation (Anderson, 1974). However, large portions of these areas are covered by protective batting ensembles. The importance of this is highly relevant since when other areas are covered by protective equipment, it is likely that heat transfer from the chest and back are vital to maintain thermal balance. It is unquestionable then that under High-stress environments heat loss from the chest and back should not be impeded. In accordance with the opinions expressed by Pascoe **et al**. (1994b), the fabric and

design of clothing worn by batsmen, particularly the shirt, should be carefully considered to augment cooling under hot and humid conditions.

TABLE XVIII: **Post-hoc summary of mean skin temperature responses each Over, indicating differences between specific conditions.**

	MST			
Over	**I to VII****			
	HFG	HNG	LFG	LNG
HFG	-	§	§	§
HNG		-	§	§
LFG			-	§
LNG				-

Note: Asterisks code as in Figure 29 above.

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear; LNG = Low No-Gear.

The forehead temperature responses throughout the work-bout are depicted in Figure 30 and the post-hoc summary (Table XIX) indicates significant differences between conditions. Under the High-stress conditions the temperature increased significantly from the 1st to the 7th Over, whether a helmet was worn or not. However, the helmet clearly exacerbated this effect, resulting in significantly higher forehead temperatures, from start to finish, when the head was covered. These findings are consistent with those of King **et al**. (2002). Interestingly, forehead temperature under the LFG followed a similar trend and showed consistent increases over the bout with a significant difference between the first and last Over. None of these three (HFG, HNG, LFG) conditions appeared to reach a plateau. However, the rate of increase under Low-stress conditions, where a helmet was worn, was greater than High conditions without a helmet. As a result, the significant difference between HNG (34.75 ± 0.99 °C) and LFG (33.40 ± 1.41 °C) evident at the beginning of the activity gradually diminished and by the 4th Over had disappeared. Forehead temperature

under the LNG condition decreased until the 4th Over and then started to rise again, but failed to reach an equilibrium point by the end of the activity.

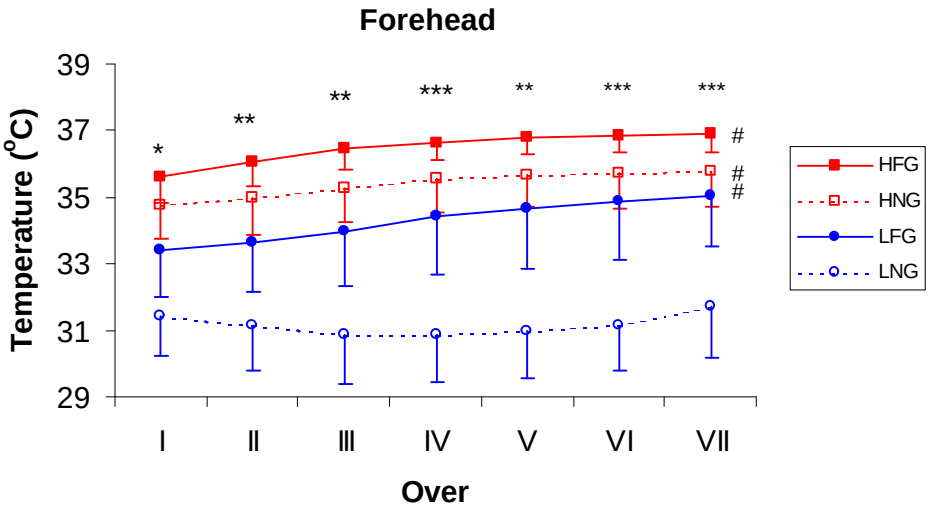

FIGURE 30: **Forehead temperature for each Over during the batting work-bout.**

Note: Post-hoc analysis, Table XIX indicates significant differences (*, ** and ***) between specific conditions.
# denotes significant difference between initial and last Over ($P < 0.05$).

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear; LNG = Low No-Gear.

TABLE XIX: **Post-hoc summary of forehead temperature responses for each Over, indicating differences between specific conditions.**

	Forehead[1]											
Over	**I***				**II to V****				**VI to VII*****			
	HFG	HNG	LFG	LNG	HFG	HNG	LFG	LNG	HFG	HNG	LFG	LNG
HFG	-	ND	§	§	-	§	§	§	-	ND	§	§
HNG		-	§	§		-	§	§		-	ND	§
LFG			-	§			-	§			-	§
LNG				-				-				-

Note: Asterisks code as in Figure 30 above.
[1] The sole exception was a finding of significant difference HFG vs. HNG and HNG vs. LFG in Over IV.

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear, LNG = Low No-Gear.

These data suggest that regardless of whether a helmet is worn or not, a substantial amount of heat must be dissipated from the head. However, wearing a helmet impedes heat loss from the head, resulting in significantly higher forehead temperatures. It is suggested that helmet design be investigated in order to improve dry and evaporative cooling as well as comfort. Davis **et al**. (2001) observed that although ventilated safety helmets do not cause a significantly smaller physiological burden, they do, in effect, improve thermal comfort. Cricket helmets are ventilated but the holes are small and the outcome for heat transfer mechanisms and comfort are unknown. Improving ventilation may or may not be advisable since impact protection of cricket helmets has been already questioned (Stretch, 2000) and no adjustment to the helmet should ever compromise safety.

Gisolfi **et al**. (1988) examined the effects of wearing a helmet on various physiological parameters (heart rate, core and skin temperature and RPE) while cycling, and found wearing a helmet did not significantly affect any of the measured parameters. In contrast to cycling, the cricket helmet is worn in conjunction with several other pieces of protective equipment. In addition convective cooling in batting activity is far less than cycling. Therefore the combined effect of covering large portions of the body surface area by protective equipment does appear to have a significant influence on physiological responses, namely MST (Figure 18), heart rates (Figure 19) and sweat losses (Figures 20 and 21).

Cardiac Responses – Heart Rate vs. Overs

For the purposes of this study the batters' heart rate responses were used to reveal the thermal strain experienced by the cardiovascular system. The effect of batting in

High temperatures places a greater thermal load on cricketers, and this load is more pronounced whilst wearing protective gear. The increased skin temperatures observed in the forearm, shin and possibly head are likely to increase vasodilatation and elevate local skin blood flow in these regions. The associated reduction in central venous volume is likely to increase cardiovascular strain while batting.

Average heart rate responses for the entire exercise period indicated that the independent effects of environment (Figure 11) and clothing (Figure 19) both had a significant impact on cardiovascular strain. The effects of the specific conditions on heart rate responses for each Over are described and compared in Figure 31 and Table XX respectively. The typical pattern of heart rate responses for each specific condition is characterised by a fairly rapid increase between the 1st and 2nd Over, followed by a more gradual increase until around the 6th Over. At this stage mean heart rate appears to be relatively consistent. If this work rate was continued for a longer period than used in the trials, it is possible that this stable mean heart rate may rise gradually. “Cardiovascular drift” is a characteristic phenomenon of prolonged activity in warm environments (Saltin and Stenberg, 1964; Rowel, 1974; Gisolfi **et al**., 1988), although this occurrence is usually noted in constant aerobic activities.

At the start of batting the heart rate during the 1st Over was no different under the four specific conditions. Differences become apparent from the 2nd Over onwards, but only after 4 Overs of batting were significant differences patent between FG and NG under High environmental stress conditions. As the activity progressed there was a continual divergence of heart rate responses, although in the final Over, there was

still no difference in cardiovascular strain between clothing conditions under the Low environmental stress condition. It is clear that for each specific condition, mean heart rate was highest in the final Over and batsmen experienced the greatest strain when wearing Full-Gear in High-stress conditions. In the closing Over of the bout, mean heart rate was elevated to 151 ± 11 bt.min^{-1}. At this juncture HFG conditions were significantly greater than HNG conditions (145 ± 11 bt.min^{-1}), which in turn was significantly greater than both Low-stress conditions, FG (138 ±12 bt.min^{-1}) and NG (134 ± 11 bt.min^{-1}). No differences were observed between clothing conditions at any stage of the bout under Low-stress conditions.

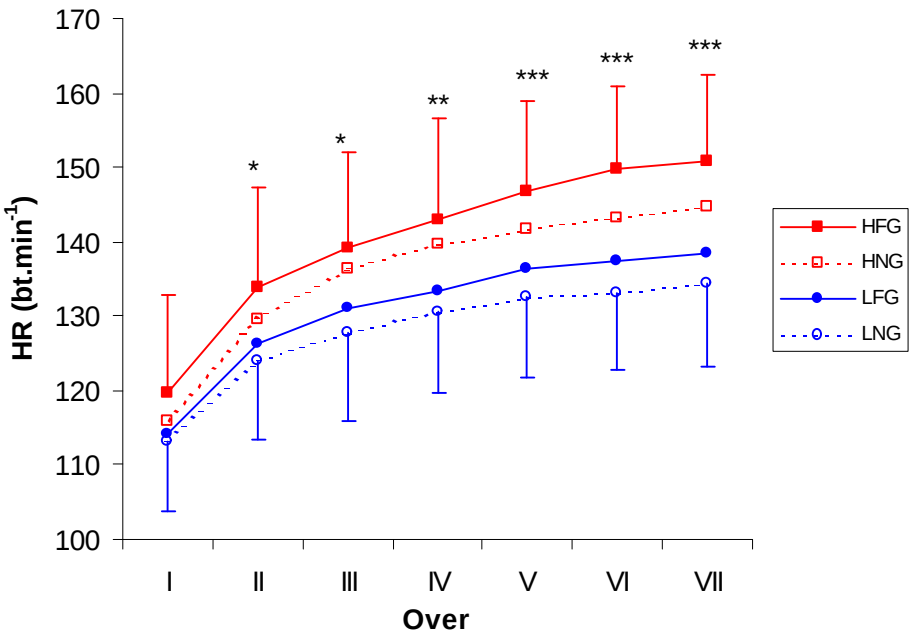

FIGURE 31: **Mean heart rate responses for each Over during the batting work-bout.**

Note: Post-hoc analysis, Table XX indicates significant differences (*, ** and ***) between specific conditions.

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear, LNG = Low No-Gear.

TABLE XX: **Post-hoc summary of mean heart rate each Over, comparing specific conditions.**

	Mean Heart Rate[1]											
Over	**II to III***				**IV****				**V to VII*****			
	HFG	HNG	LFG	LNG	HFG	HNG	LFG	LNG	HFG	HNG	LFG	LNG
HFG	-	ND	ND	§	-	ND	§	§	-	ND	§	§
HNG		-	ND	ND		-	ND	ND		-	ND	§
LFG			-	ND			-	ND			-	ND
LNG				-				-				-

Note: Asterisks code as in Figure 31 above.
[1] there was no differences between specific conditions for Over I.

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear; LNG = Low No-Gear.

The significant increases in heart rate as a result of the environmental stress were not unexpected since the impact of ambient conditions on cardiovascular responses is well established during various activities (Lind, 1963; Rowel, 1974; Pandolf **et al**., 1975; Vogt **et al**., 1981). In addition, the findings of several studies (Gore **et al**., 1993; Nevill **et al**., 1995; Morris **et al**., 1998) involving intermittent activity support the present work regarding the influence of environment on heart rate responses. On top of the environmental influences, protective cricket padding was shown to further elevate skin temperatures under High-stress conditions, a response which has been encountered during activities where protective ensembles are employed (Mathews **et al**., 1969; Baker **et al**., 2000; Ftaiti **et al**., 2001). Since no differences were evident between FG and NG under Low-stress conditions, it is speculated that load carried and mechanical factors played less of a part than the increased thermal stress imposed by protective gear. The overall impact of environmental conditions and protective clothing increases the skin temperatures, particularly those areas directly covered, and was likely to induce pooling of blood. It is possible that the increased heart rate observed was due to typical compensatory responses of the body to assist

in preventing a drop in the cardiac output. Ultimately this may have a negative impact on cardiovascular efficiency, although this does not necessarily imply that there will be a reduction in any aspect of cricket performance.

Recovery Heart Rate

Parsons (1993) indicated that recovery heart rate could provide a measure of thermal strain, which can be related to deep body temperature. Figure 32 illustrates anticipatory heart rate responses prior to the batting trials and recovery heart rate following the activity. There were no differences in anticipatory heart rate between the specific conditions, demonstrating that neither the environment nor clothing conditions had an influence over pre-exercise responses. It is clear that the cardiovascular strain was the same for each of the specific conditions at the start of the activity. Anticipatory rates ranged from 97 to 106 $bt.min^{-1}$, which were significantly higher than the baseline heart rate (58 $bt.min^{-1}$). The significant elevation is due to the batters performing 2 to 3 minutes of active warm-up (jog and stretch) prior to the exercise-bout.

Note that the recovery period following the batting work-bout was one of active recovery. On completion of the work-bout subjects removed protective gear, returned to the outdoor test area and assisted in operating the bowling machine. Consequently the recovery period could not be strictly standardised, but was similar to match conditions where a player is seldom totally inactive following batting. Data from the recovery period were intended to indicate how heart rate responses were likely to normalise following a bout of batting. The recovery heart rate trend observed under all conditions shows a fairly rapid drop in heart rate from the end of the bout

until the 3rd period (minutes 11 to 15). Thereafter the heart rate levels off and remains fairly constant. Under all specific conditions it took about 11 to 15 min for the heart rate to reach pre-exercise anticipatory level. Accordingly it is recommended that for the cardiovascular system to recover adequately from a relatively short bout of intense batting requires between 11 and 15 min of active recovery.

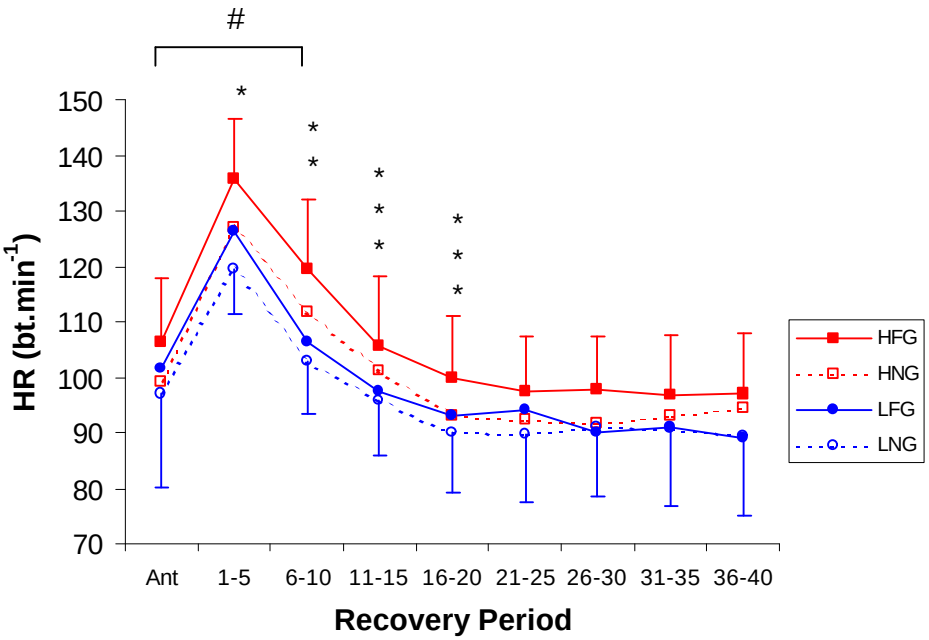

FIGURE 32: **Anticipatory and average recovery heart rate responses for successive 5-min periods after completion of the batting work-bout.**

Note: Post-hoc analysis, Table XXI indicates significant differences (*, ** and ***) between specific conditions.
# denotes that for all conditions anticipatory heart rate was significantly lower ($P < 0.05$) than recovery heart rate for specified period.

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear; LNG = Low No-Gear.

TABLE XXI: **Post-hoc summary of recovery heart rate responses, successive 5-min periods, after completion of the batting work-bout, comparing specific conditions.**

	Recovery Heart Rate[1]											
PERIOD	**O-5 min***				**6-10 min****				**11-20 min*****			
	HFG	HNG	LFG	LNG	HFG	HNG	LFG	LNG	HFG	HNG	LFG	LNG
HFG	-	§	§	§	-	ND	§	§	-	ND	ND	§
HNG		-	ND	§		-	ND	§		-	ND	ND
LFG			-	ND			-	ND			-	ND
LNG				-				-				-

Note: Asterisks code as in Figure 32 above.
[1] There was no difference between specific conditions for the period 21-40 min or for anticipatory responses.

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear; LNG = Low No-Gear.

During the 1st recovery period a difference was observed between clothing conditions under High environmental stress conditions, yet there was no difference between clothing conditions under conditions of Low environmental stress. The environment was responsible for significantly higher heart rate. The High-stress conditions resulted in higher heart rate than Low-stress conditions for FG or NG conditions. Under exercising conditions, the highest heart rates, peak and average, were observed under HFG conditions. Therefore it was expected that the combination of High environmental stress and protective clothing would result in the highest heart rate for each specific condition over the entire recovery period. As the recovery period progressed, the differences between conditions were reduced and by the 5th period (21 to 25 min) there were no differences between any of the conditions.

During cricket matches the typical recovery intervals are 5 minutes (drinks), 20 minutes (tea) and 40 to 45 minutes (lunch) (ICC, 1998). It therefore seems clear that under hot conditions where activity has been relatively intense, the drinks breaks will

not allow sufficient time for cardiovascular responses to return to pre-activity levels. Therefore batsmen are advised to regulate work rate otherwise they run the risk of not recovering adequately. This may result in fatigue under situations where batting is prolonged, particularly under High-stress conditions. However, for short intense batting bouts, the tea and lunch breaks provide sufficient recovery time.

Fluid Loss

Sweat losses and sweat rates are represented in absolute and relative terms in Figure 33, and Table XXII denotes the post-hoc summary of specific conditions. It is shown that for all sweating responses the specific conditions differed significantly, with the exception of LFG vs. LNG. The various components of sweat depletion were calculated from absolute sweat loss over the activity, therefore the configuration of the specific conditions remained consistent for sweat losses and sweat rates. For sweat loss and sweat rate responses, the pattern of the specific conditions was analogous to those observed for the other physiological parameters (MST and exercise heart rate). High environmental stress conditions resulted in sweat losses and sweat rates that were significantly greater than observed under Low environmental stress conditions. Within High-stress conditions, wearing Full-Gear produced a significantly higher sweating response than wearing No-Gear. The higher ambient conditions are undoubtedly the primary factor responsible for the higher sweat rates, shown by virtue of the fact that HNG conditions were significantly greater that LFG. Physiological strain attributed to sweating is increased with higher ambient conditions and concurs with the findings of Lind (1963). Additionally, wearing protective gear amplified sweating, which has been observed by Ftaiti **et al**. (2001)

and King **et al**. (2002), although this was only significant under High-stress conditions.

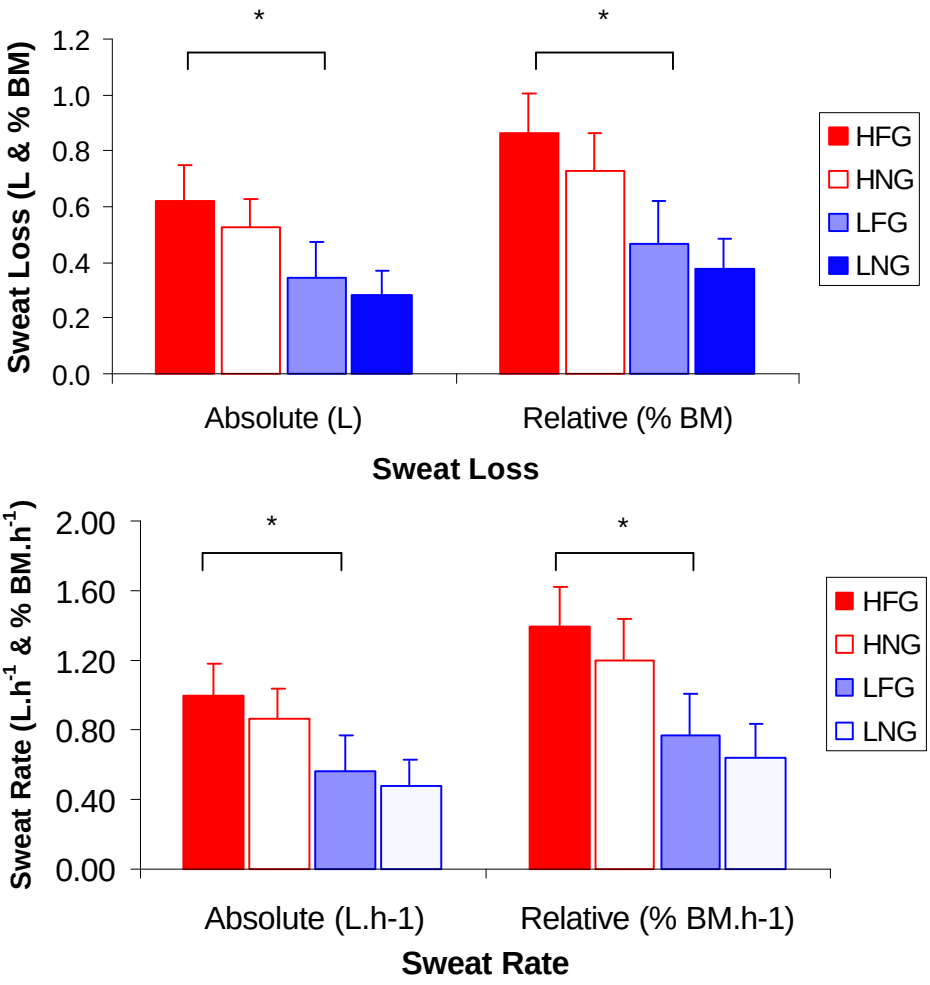

FIGURE 33: **Estimated sweat losses, absolute (L) and relative (% BM) and sweat rates, absolute (L.h^{-1}) and relative (% BM.h^{-1}) during batting activity.**

Note: Post-hoc analysis, Table XXII indicates significant differences (*) between specific conditions.

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear; LNG = Low No-Gear.

Metabolic rate has been identified (Sawka and Pandolf, 1990; Noakes, 1992) as an important factor in determining the sweat rate. Metabolic heat was not deemed to have had a major impact on differences between specific conditions during batting, particularly HFG and LFG, because the work rates were standardised. However,

heart rates were significantly different between conditions. There is a possibility that wearing protective ensembles produced increases in metabolic rate as a result of additional load and reduced mechanical efficiency. This is in conjunction with the increased thermal stress of protective kit. Earlier assumptions regarding cardiac variables implicate thermal stress as being responsible for increased heart rate responses, although it is difficult to determine from the data what portion of the increased cardiovascular demands were related to increased thermal stress or to mechanical and loading factors.

TABLE XXII: **Post-hoc summary of absolute and relative estimates of sweat loss and sweat rate, indicating differences between specific conditions.**

	Sweat Losses and Sweat Rates (Absolute and Relative)			
	HFG	HNG	LFG	LNG
HFG	-	§	§	§
HNG		-	§	§
LFG			-	ND
LNG				-

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear; LNG = Low No-Gear.

Christie **et al**. (In Press), using an identical work-bout as the present investigation, examined the energy expenditure of batsmen in Full-Gear. The mean energy expenditure for the duration of the bout was 2536 $kJ.h^{-1}$. The environment in which their testing occurred was temperate and fell between the High and Low conditions of the present study. A comparison of the mean energy expenditure of the batting activity with metabolic rates of distance runners (Dennis and Noakes, 1999) indicates that at this rate of heat production runners are estimated to lose 1.10 $L.h^{-1}$. This level is actually higher than that observed for the fully clad batters in the present study,

which ranged between 1.00 and 0.57 $L.h^{-1}$ for the High and Low conditions respectively.

As pointed out previously, sweat rate is influenced by metabolic rate and therefore internal temperature, although it has been shown that skin temperature alters the threshold for sweating. Reporting on the influence of the internal and skin temperature relationship on sweat response, Nadel (1979) observed that for a given core temperature, local sweat rate was greater when skin temperature was higher. Thus the higher skin temperatures produced while batting in protective gear and High-stress environmental conditions were likely to initiate the sweating response earlier. Additionally, among the specific conditions of supposedly similar metabolic rates, higher skin temperatures would produce increased local sweating and therefore greater sweat production. The increased skin temperatures observed were related to higher environmental stress and increased thermal stress imposed by protective layers impeding heat loss. It is suggested that thermal stress mediated by environment or clothing are the primary contributing factors to increased sweat rates. However, there is probably also a contributing factor of the increased metabolism, but in all likelihood this involvement was small.

During this simulated batting activity it was evident that the sweat losses were greater than those found in the literature. Gore **et al**. (1993) reported that batting in temperatures of 22 °C and 26 °C (WBGT) elicited mean sweat rates of 0.47 and 0.6 $L.h^{-1}$ respectively. For similar ambient conditions both these rates are lower than those shown for FG and NG under High-stress conditions. This could be explained by the intensity of the workload investigated. The present research was intended to

simulate a one-day work rate, which was probably more intense than that investigated by Gore **et al**. (1993). Their study focused on a work-bout representative of a 4 to 5-day cricket match, which is generally of a lower intensity (Fletcher, 1955; Noakes and Durandt, 2000; Christie **et al**., In Press), again emphasising the importance of metabolic output in determining sweat response of athletes.

Hypohydration of 2 percent of body mass is the critical level at which significant physical and mental performance deficits occur (Latzka and Montain, 1999). Since performance has been shown to be impaired with dehydration, it is worthwhile determining the possible levels of hypohydration of batters. Repeating the earlier method used to estimate overall hypohydration level of batsmen, a 75 kg cricketer under HFG conditions, will be hypohydrated by 1.8% BM after 2.5 hours of batting, which matched the levels reported by King and Christie (2001), and King **et al**. (2002). Thus an opening batsman in a one-day match may near the critical level of hypohydration in the latter stages of the innings, while there is still an hour left to bat. It is possible that physical capacity plus mental ability will be impaired. Thus in the final crucial stages of the innings batsmen may under-perform or worse still, give their wicket away, thereby bringing a new batsman to the crease. Based on estimates above, significant hypohydration is only likely to occur in one-day matches under moderate-to-hot environmental conditions.

PERCEPTUAL VARIABLES

Rating of Perceived Exertion (RPE)

Ratings of perceived exertion were recorded after each Over during batting trials. Batters were asked to provide an overall rating indicating how demanding they

perceived the trial to be. The mean perceived exertion ratings for each Over of the batting activity are represented in Figure 34, while the differences between conditions are represented in the post-hoc analysis (Table XXIII). The RPE scores during each trial were similar at completion of the 3rd Over, after which they rose steadily under both High-stress conditions (FG and NG), but for both Low-stress trials they started to level off. These divergent trends resulted in significant differences between environmental conditions; the longer the bout progressed, the larger the discrepancy between High and Low trials. Initially differences were only evident between HFG and LNG, but by completion of the 6th Over, both High-stress trials were significantly greater than both Low-stress trials. Within each of the environmental trials there were no differences between Full-Gear and No-Gear conditions.

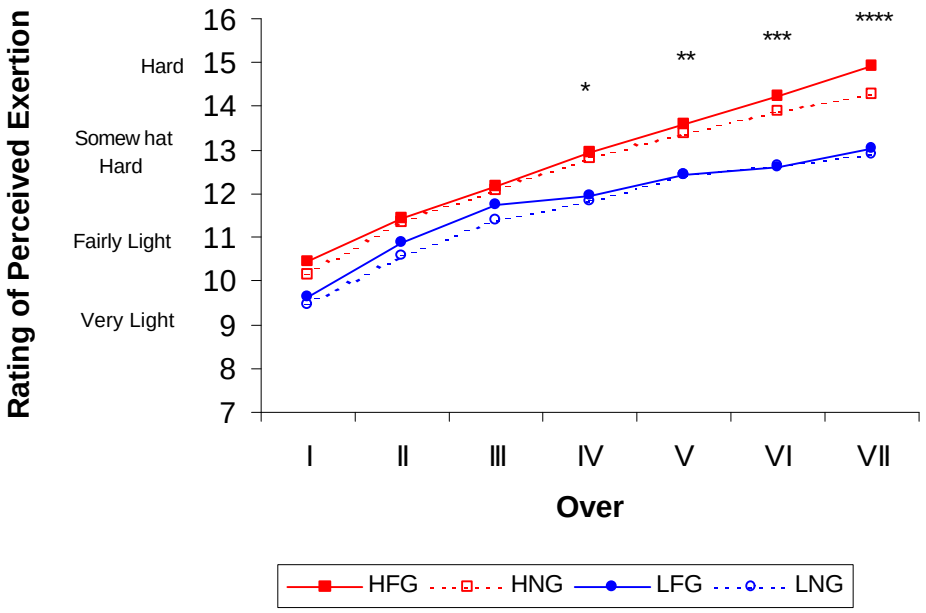

FIGURE 34: **Rating of perceived exertion over the batting work-bout.**

Note: Post-hoc analysis, Table XXIII indicates significant differences (*, **, *** and ****) between specific conditions.

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear, LNG = Low No-Gear.

These results substantiate the earlier findings utilising two-way analyses of variance, that environment, and not clothing worn, affected the perception of effort while batting. The increase in perceptual strain is supported by the fact that there was evidence of greater physiological strain due to higher environmental stress. While the effort sense seemed to identify the demands of High environmental stress, the subjects did not appear to perceive the wearing of protective gear as adding significantly to the required effort.

TABLE XXIII: **Post-hoc summary of mean RPE responses each Over, comparing specific conditions.**

	Rating of Perceived Exertion[1]											
Over	**IV***				**V****				**VI to VII*****			
	HFG	HNG	LFG	LNG	HFG	HNG	LFG	LNG	HFG	HNG	LFG	LNG
HFG	-	ND	ND	§	-	ND	§	§	-	ND	§	§
HNG		-	ND	ND		-	ND	ND		-	§	§
LFG			-	ND			-	ND			-	ND
LNG				-				-				-

Note: Asterisks code as in Figure 34 above.
[1]There were no significant differences between specific conditions for Overs I to III and the sole exception to the analyses above was (****) a finding of no difference HNG vs. LFG in Over VII.

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear; LNG = Low No-Gear.

The results of the present study indicate that not only was simulated cricket batting activity under Low environmental stress conditions physically less taxing than under High environmental stress conditions, but subjects also perceived it to be significantly less demanding. In examining data from the present study of Full-Gear trials under High and Low conditions, Todd **et al**. (In Press) argued that RPE could be used as an effective tool in the assessment of the physical workload of cricket batting activity. Rating of perceived exertion may give a general indication of batters' perceptions of effort, but it seems to underestimate the impact of clothing.

Correlations with RPE and physiological variables recorded related mean values of heart rate and MST for each Over with mean RPE each Over. Heart rate and RPE means were highly related with R^2 values for trials of 0.94, 0.95, 0.99 and 0.97 for HFG, HNG, LFG and LNG respectively. These findings are probably not that surprising since any physiological variable that is linearly related to exercise intensity will correlate highly with RPE (Hetzler **et al**., 1991). Skin temperature means were also highly correlated and exhibited R^2 values of between 0.88 and 0.98. All physiological relationships showed a positive correlation with RPE, with the exception of MST for LNG trials (R^2 = -0.88), which produced an inverse relationship.

It is clear from the data that changes in the environment influence RPE, but the mechanism responsible for this is undecided. Rating of perceived exertion is related to MST and heart rate. Consequently, these variables were identified as possible mediators of effort perception while batting. Various other variables have also been previously identified as being related to effort sense. These include central or cardiopulmonary factors (oxygen uptake, respiratory rate and ventilatory rate) and peripheral or metabolic factors (blood lactate levels, blood and/or muscle pH, mechanical strain, muscle damage, core temperature and carbohydrate availability) (Hampson **et al**., 2001). The present investigation is unable to determine the extent that these factors may have contributed to the perceptual rating, but it is acknowledged that a network causality of factors, physiological or otherwise, determining changes in RPE extend above and beyond those examined.

Two interesting observations become apparent when the RPE responses were examined in relation to the actual physical requirements of the task. Firstly, the

performance component of the bout required batters to run as fast as possible (maximally) on each sprint; however, they did not rate it maximally. Initially the perceived effort of the task was rated as 10 (very light to fairly light) and by the end of the bout the rating was 14 (somewhat hard to hard) and 13 (somewhat hard) under High-stress and Low-stress conditions respectively. Even though RPE is recognised as being related to exercise intensity (Skinner **et al**., 1976), this is generally more pertinent to continuous activity.

The sub-maximal rating by players does not reflect the actual physical effort required to complete a short (5.73 to 5.89 s) maximal sprint activity. Instead, effort sense may be initially related to certain sensory cues of physiological origin. Mean cardiac responses were clearly sub-maximal at the start of the testing session and increased gradually, although the relationship with skin temperatures was less obvious. Hampson **et al**. (2001) suggest that no single physiological variable can consistently explain perception of effort. However, at high exercise intensities, ventilation and blood lactate levels seem to possess a particularly strong relationship with RPE. At the start of exercise, lactate accumulation would have been low and these levels may have built up as the bout progressed. It is speculated that core temperature and catecholamine levels may also have increased.

Secondly, it has been identified that the actual physical effort (sprint times) remained unchanged although perception of effort increased as the bout progressed. This outcome may point towards the fact that subjects did not fully recover between sprint sets. The sub-optimal recovery is also reflected in physiological responses, specifically heart rate and to a lesser extent MST. Both variables failed to return to

baseline levels within recovery periods between Overs. Mean data for heart rate and MST were both identified as having a strong positive correlation with RPE. It is possible that in addition to the steady upward drift of various physiological processes that the gradual accumulations of blood lactate and catecholamines also contributed to the subjects' effort sense. The sensation of strain within the limbs must not be overlooked, particularly in activities where there is a localised application of large amounts of muscular force (Pandolf and Nobel, 1973; Cafarelli, 1977), and possible muscle damage resulting from eccentric contraction (Pandolf **et al**., 1978) when decelerating to turn in the crease and at the end of a run. However, the levelling off under Low-stress conditions from about the 5th Over may be attributed to psycho-physical cues, namely thermal sensation and comfort, described in detail below.

Thermal Sensation and Thermal Comfort

Thermal sensation ratings taken at the end of each Over are depicted in Figure 35. There were differences (Table XXIV) between High-stress trials and Low-stress trials the entire way through the work-bout, yet there were no differences between clothing trials within either environmental condition during the activity. Thermal sensation ratings increased from the start of the bout, with the High and Low-stress trials running almost parallel but significantly lower until the 5th Over. At this time FG and NG trials under the Low-stress environmental condition started to stabilise, while High-stress trials failed to do so, thereby causing further disparity. The batters' thermal sensation ratings were clearly influenced by the environment, yet protective gear did not have a significant impact.

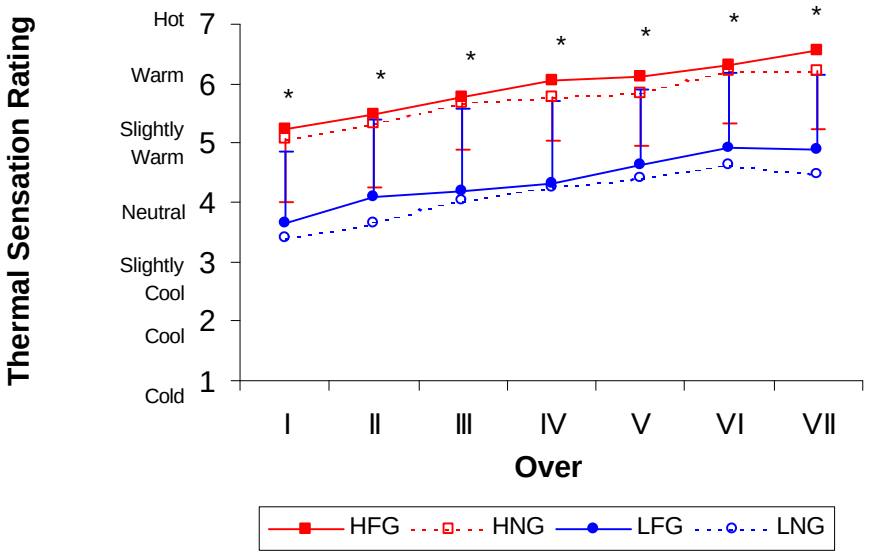

FIGURE 35: **Thermal sensation ratings over the batting work-bout.**

Note: Post-hoc analysis, Table XXIV indicates significant differences (*) between specific conditions.

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear; LNG = Low No-Gear.

TABLE XXIV: **Post-hoc summary of thermal sensation ratings for each Over, comparing specific conditions.**

	Thermal Sensation Rating			
Over	**I to VII***			
	HFG	HNG	LFG	LNG
HFG	-	ND	§	§
HNG		-	§	§
LFG			-	ND
LNG				-

Note: Asterisks code as in Figure 35 above.

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear; LNG = Low No-Gear.

Thermal sensation scores described how the batters felt during the activity, but it was deemed necessary to include how they would like to feel while batting. Therefore, in addition to the adaptations to thermal sensation during the 7 Overs, the overall incidence of thermal comfort ratings is represented in Figure 36. It would appear that protective gear had minimal impact on overall thermal sensation and thermal comfort

during the batting activity, as there were no differences between clothing trials within either of the environmental conditions. However, the results illustrate that under the High-stress conditions, over 70% of the responses for FG and NG trials indicated that batters would prefer to be cooler. There were only minimal responses indicating status quo, i.e. favour no change, and an even smaller number preferring warmer conditions. It should be noted that these affective responses were prevalent at the start of activity, and the incidence of warmth discomfort became more frequent the longer the bout progressed. Under Low-stress conditions, the incidence of thermal comfort was more common than under High-stress conditions, 63 and 58% of responses for FG and NG trials respectively indicated comfort. The results of overall incidence suggest that under Low-stress conditions 18 to 22% of respondents preferred cooler conditions, while 15 to 24% preferred warmer environs. There was clear evidence of personal differences under similar ambient conditions when batters exhibited varied perceptual and affector responses, although the inclination for warmer conditions was more prevalent at the start of activity and the incidence of preference for cooler conditions was greater toward the end of the bout. This pattern was noted for both High and Low-stress environments, but was more discernible under Low-stress. In all probability, this is in part due to the warm-up effect of the work-bout. As the bout progressed, changes within the physiological system became more pronounced, specifically skin temperatures and heart rate. Certain physiological variables have been linked to thermal sensation and comfort, namely core temperature, skin temperature, heart and sweat rate, specifically skin wettedness. Clothing factors have also been linked to thermal comfort, although it is clear that the protective gear did not have a significant effect on sensation or comfort.

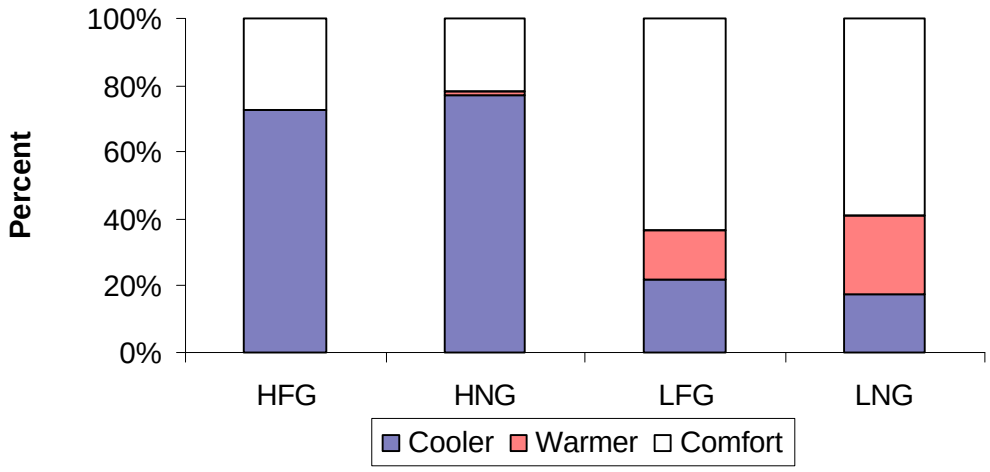

FIGURE 36: **Incidence (%) of thermal comfort ratings for specific conditions.**

Wearing protective layers did not influence perceived exertion, thermal sensation or thermal comfort of the subjects in this study, which implies that protective gear did not place an undue psycho-physiological burden on the batters. However, it must be noted that the duration of trials was relatively short and as such, the effects of longer exposure may well impact on the psycho-physical perceptions and ultimately, performance. Further research is required to determine the effects of prolonged batting stints. It is patent that the environment does affect these perceptual and affector responses. Strategies should be devised to reduce the psycho-physical stress associated with batting under High-stress environmental conditions. This is particularly relevant since the conditions utilised within the present study are not as severe as frequently encountered in professional cricket matches.

PERFORMANCE VARIABLES

Sprint Performance

Fractionated sprint times for the specific conditions are portrayed in Table XXV, and differences between conditions are represented by the post-hoc summary (Table XXVI). Sprint times were for the most part influenced by the wearing of

protective gear, although turn times were unaffected by either clothing or environmental conditions. Under High-stress conditions, there were differences between FG and NG for fractionated sprint times. Similarly, differences between clothing conditions were observed under Low environmental stress. The padded trials were performed at slower speeds than No-Gear trials; this was true for High or Low-stress conditions. Two-way analyses suggest that sprint times were in fact significantly faster under High-stress than Low-stress conditions. However, data comparing the specific conditions indicate that the environment only had an impact on sprint performance during SPRINT 1, where differences between HFG and LFG were evident. There were also differences between LFG and HNG, but these were to be expected since it has been shown that clothing reduced sprint times significantly.

TABLE XXV: **Mean fractionated sprint times during the work-bout for specific conditions.**

	Fractionated Sprint Times (s)			
	SPRINT 1	**SPRINT 2**	**TURN**	**OVERALL**
HFG	2.37 ±0.09 **2.37**	2.38 ±0.10 **2.37**	1.09 ±0.08 **1.10**	5.85 ±0.20 **5.84**
HNG	2.30 ±0.07 **2.29**	2.28 ±0.10 **2.31**	1.09 ±0.09 **1.11**	5.67±0.17 **5.68**
LFG	2.44 ±0.08 **2.43**	2.39 ±0.11 **2.41**	1.11 ±0.09 **1.10**	5.94±0.19 **5.99**
LNG	2.36 ±0.08 **2.38**	2.32 ±0.10 **2.33**	1.10 ±0.11 **1.07**	5.78 ±0.21 **5.81**

Means ± SD, median for non-parametric statistics in **bold**.

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear, LNG = Low No-Gear

Speed and agility are capabilities essential for batsmen. It was clearly evident that wearing protective gear reduced running speed and agility performance. Since it has been observed that protective gear resulted in greater physiological stress on batters,

it would be convenient to suggest that this stress was partly responsible for slower running speed. However, the results indicate that the environment generally placed a greater physiological demand on the cricketers than protective gear, but for the most part sprint performance was unaffected by the environment. The padding probably disrupted locomotion, thereby slowing sprint times.

TABLE XXVI: **Post-hoc summary for mean fractionated sprint times during the activity, comparing specific conditions.**

	Fractionated Sprint Times[1]											
Over	**SPRINT 1**				**SPRINT 2**				**OVERALL**			
	HFG	HNG	LFG	LNG	HFG	HNG	LFG	LNG	HFG	HNG	LFG	LNG
HFG	-	§	§	ND	-	§	ND	ND	-	§	ND	ND
HNG		-		ND		-	§	ND		-	§	ND
LFG			-	§			-	ND			-	§
LNG				-				-				-

Note: [1] For TURN times there were no significant differences between specific conditions.

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear, LNG = Low No-Gear.

The gear used was comparable to that used by first class cricketers, although the equipment available from various manufacturers differs with respect to design, weight and materials used. Certain manufacturers produce padding, specifically leg-guards, that are supposedly lightweight and of a superior design. It is claimed that they improve running speed. There are many brands of gear available and it may be worthwhile investigating whether certain brands afforded batsmen a greater advantage than others.

In most cases, the environment had a limited impact on sprint performance. The only exception was for SPRINT 1, which was significantly faster under higher ambient conditions. This would support the suggestion that slower running times were not a

result of greater thermal stress and disruptions to physiological processes. Even though High-stress conditions placed a substantial stress on various physiological mechanisms, these alterations did not necessarily hinder sprint performance. It is more likely that mechanical factors were responsible for the decline in speed.

Batting Specific Reaction Time

Choice reaction times (Figure 37) were not influenced by clothing conditions or environment, as there were no differences between specific conditions for pre- or post-reaction times. Even though two-way analysis revealed differences between pre and post times under Low conditions (Figure 17), as well as under FG conditions (Figure 25), when the specific conditions were assessed, no differences were evident. Thus neither clothing nor environment had an effect on reaction times and did not cause differences between pre and post times.

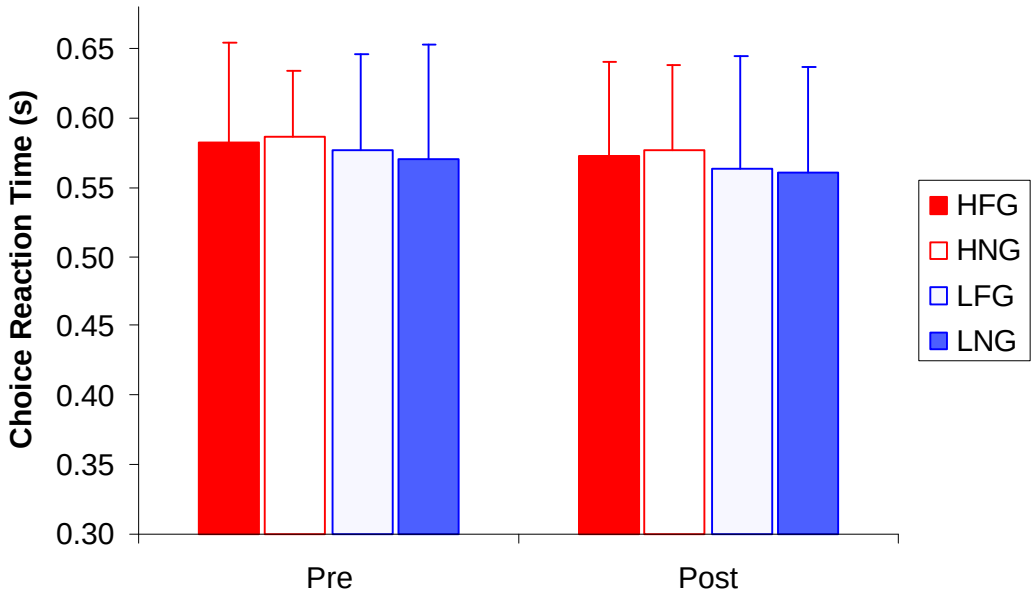

FIGURE 37: **Pre- and post-batting specific reaction times.**

HFG = High Full-Gear; HNG = High No-Gear;
LFG = Low Full-Gear; LNG = Low No-Gear.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

Cricket matches are sometimes played under extremely hot and humid climatic conditions (Gore **et al**., 1993; Burke and Hawley, 1997; Noakes and Durandt, 2000; King, 2001). In many instances these environmental conditions would be considered too severe if encountered in other sporting codes such as running, American football or youth soccer (Mathews **et al**., 1969; Elias **et al**., 1991; ACSM, 1996), nevertheless play goes on. In addition to the harsh climate, batsmen must wear protective garments, which are likely to hinder heat loss. Even with these apparently adverse circumstances the incidence of thermal injury is rare in cricket. This is in all probability due to participants modifying work rates, which in turn will modify heat production. Even though the imposed thermal burden is tolerated, this stress may influence various physiological and psycho-physical functions of the players, with the ultimate effect being a deterioration in performance.

The present study hypothesised that high-stress environments and protective garments would increase the physiological and perceptual strain during batting participation, resulting in a decrement of some aspects of cricket performance.

In addition to the effects of clothing and environment there are limited data regarding the general demands on batsmen during Limited Over matches. It is hoped that the information gleaned from this investigation may be utilised for future strategies and

interventions undertaken to reduce the strain experienced by the players and to improve performance in cricket.

SUMMARY OF PROCEDURES

In an attempt to investigate batsmen under conditions that are representative of the natural environment, the present study was conducted out of doors, utilising the sports facilities of Rhodes University, Grahamstown. The study investigated a standardised batting work-bout under four experimental conditions. The work-bout was presumed to represent the upper end of the activity level encountered by batsmen during Limited Over matches. The four experimental batting conditions involved different combinations of environmental stress and garments worn.

Two clothing conditions were examined, with subjects wearing: 1) a combination of Full Protective Gear and general cricket clothing (FG), or 2) general clothing only with No Protective Gear (NG). Both clothing trials were conducted under separate environmental conditions involving High or Low environmental stress. Under each environmental condition both the Full-Gear and No-Gear conditions were performed on the same day, with the order of these trials being randomised for each subject.

All subjects completed each of the four trials, and therefore each served as their own control. The two trials performed on the same day were separated by a minimum period of two hours. The investigation of different environmental conditions was carried out in different climatic seasons, therefore several months separated these trials. For each subject, the time of day and order in which clothing trials were carried

out in the initial environmental condition were, as far as possible, repeated in the second. This was done in order to limit the effects of circadian rhythm.

Basic data were collected on each of 25 male cricketers (mean age 19 yr, mean stature 1768 mm, mean mass 73 kg) and the following variables were calculated, mean BMI 23.3 kg $(m^2)^{-1}$, mean RPI 424 mm.$\sqrt[3]{kg^{-1}}$, mean BSA 1.89 m^2, mean body fat 12.6%, mean LBM 64 kg. All subjects participated at first league or higher standard. Throughout the trials various physiological, perceptual and performance variables were assessed. During the experimental trial subjects received one delivery every 30 s with a total of 7 Overs, or 42 deliveries, faced. After every 3 deliveries the subject was required to perform one shuttle run bout at full pace. Batsmen ran between the two popping creases set 17.68 m apart, as on a cricket pitch. Each shuttle bout required batters to run to the opposite popping crease and then return. The 2 by 2 singles run per Over simulated the high work rate that is likely to be carried out after the 15^{th} Over in a high scoring one-day match. The 28 pitch-lengths run by the subjects was a cumulative distance of approximately 495 m. There was a 1-minute break period between each Over (every 6 balls received).

During the batting trial skin temperature, heart rate, fluid loss, RPE, thermal sensation, thermal comfort and sprint times were monitored. Skin temperatures and cardiac responses were sampled continuously throughout the trial. Cardiac responses were monitored for a further 40 minutes following the activity while the subject actively recovered. Sprint times were measured for each shuttle run bout performed, and perceptual responses were recorded at the end of each Over. Prior to, and on

completion of the experimental trial, batting specific reaction time was measured. The following variables were assessed:

1) Skin temperature of chest, forearm, shin, MST and forehead. These data were expressed as the average for the entire batting activity and mean temperature for each of the 7 Overs.
2) Cardiac responses provided anticipatory heart rate, average heart rate of the entire activity, peak heart rate during the bout and mean heart rate for each Over.
3) Estimated absolute sweat loss was used to determine absolute sweat rate, relative sweat loss and relative sweat rate.
4) Rating of perceived exertion was represented as the overall average of the work-bout and the mean of each Over.
5) Thermal sensation was expressed as the overall average of the work-bout, as a percentage of incidences during the work-bout and the mean score for each Over, while thermal comfort was represented as a percentage of incidences.
6) Fourteen sprint bouts were completed during each trial. Each sprint bout was fractioned into SPRINT 1, SPRINT 2, TURN and OVERALL sprint times. Fractionated times were expressed as the average of all 14 sprint bouts.
7) Batting specific reaction time consisted of pre- and post-activity times.

Basic descriptive statistics relative to the variables assessed were computed, providing general information concerning the sample. Two-way ANOVAs were calculated to determine whether there were differences between two environmental conditions, and whether differences existed between the two clothing conditions. One-way ANOVAs were utilised to compute differences between the four specific conditions combining clothing and environment. Tukey's post hoc analysis was used

to establish where differences lay. Student t-tests were used to determine whether there were time-based differences between the subject responses in the initial and the last Over. The same statistical method was adopted to ascertain differences between pre- and post-activity reaction time. Chi-squared analyses were computed to establish differences between selected perceptual variables, thermal sensation and comfort, expressed as a percentage of incidences. The significance level of $P < 0.05$ was employed.

SUMMARY OF RESULTS

ENVIRONMENT

The results indicate that the environment had a significant impact on most physiological variables. All average skin temperature variables (chest, forearm, shin, MST and forehead) were significantly greater under High-stress than Low-stress conditions. For cardiac responses anticipatory heart rates were not influenced by the environmental conditions; however, both average and peak heart rate were significantly higher under High-stress than under Low-stress conditions. Sweat losses and sweat rates were all significantly greater under High-stress conditions.

Perceptual responses were also altered by differing environmental conditions. The activity was perceived to be more demanding under High than under Low-stress conditions. Under High-stress conditions a RPE was found to be significantly higher than under Low-stress conditions. The High-stress conditions were perceived to be warmer than Low-stress environs. In the High conditions the average thermal sensation was significantly greater than the sensations recorded under Low

conditions. Under High stress conditions the incidence of warmth sensation was twice that of Low stress conditions.

The environment affected some, but not all performance responses. It appears as though SPRINT 1 and OVERALL sprint times were significantly slower under Low environmental stress, and no difference was observed between the two environmental conditions for TURN times or for SPRINT 2. Under High-stress conditions pre- and post-activity choice reactions times were no different than under Low-stress conditions. Reaction times were faster after the activity than before, although this difference was only significant under Low-stress conditions.

CLOTHING

Nearly all the physiological responses were affected by protective clothing. Protective batting gear significantly influenced the average skin temperature responses. Sites where protective gear was placed directly over the skin (forearm, shin and forehead) registered significantly greater temperatures. Only the chest site, which had no protective covering for either of the clothing conditions, showed no difference between clothing conditions. Despite the lack of differences at the chest, the overall effect of the increased skin temperatures brought about an increase in the MST under Full-Gear conditions. For heart rate responses there was no difference in anticipatory heart rate responses between either of the clothing conditions. However, average and peak heart rates were significantly higher when wearing Full Protective Gear than under No-Gear conditions. All fluid loss and sweat rate parameters were significantly higher when subjects wore Full batting Gear.

Protective layers did not significantly affect perceptual responses. There was no difference in RPE responses between clothing conditions, and the incidence of warmth sensation was no different between FG and NG conditions. Similarly, for average thermal sensation ratings no difference was observed between clothing conditions.

However, the protective clothing did have an impact on several performance responses. Mean fractionated sprint times were significantly slower when players wore Full batting Gear, with the exception of the TURN time. Pre- or post-activity choice reaction times were no different between Full-Gear and No-Gear conditions, although under Full-Gear conditions pre-activity reaction times were significantly slower than post-activity times.

HYPOTHESES

ENVIRONMENTAL EFFECTS

In respect of hypothesis 1 (a): the results force the rejection of the null hypothesis ($ì_H = ì_L$ [physiological]). Physiological variables were affected by the environmental conditions.

In respect of hypothesis 1 (b): the results again force the rejection of the null hypothesis ($ì_H = ì_L$ [perceptual]). All perceptual responses were altered as a result of different environmental loads.

In respect of hypothesis 1 (c): the null hypothesis ($ì_H = ì_L$ [performance]) is rejected in respect of sprint performance, but tentatively retained in respect of reaction time.

Sprint times were significantly different as a result of the environmental influence; the only exception was between SPRINT 2 and TURN times. Also there were no differences in batting specific reaction times between High and Low stress conditions.

CLOTHING EFFECTS

In respect of hypothesis 2 (a): the results force rejection of the null hypothesis ($ì_{FG} = ì_{NG}$ [physiological]). The exception to these findings was for chest temperature.

In respect of hypothesis 2 (b): the null hypothesis is retained ($ì_{FG} = ì_{NG}$ [perceptual]) as there were no differences in RPE, thermal sensation or thermal comfort, attributable to gear worn.

In respect of hypothesis 2 (c): the null hypothesis ($ì_{FG} = ì_{NG}$ [performance]) is rejected in respect of sprint times. There were, however, no differences between TURN times while sprinting in different clothing conditions. The null hypothesis is therefore tentatively retained in respect of batting specific reaction times, which showed no differences between clothing conditions.

Two-way analyses reveal that both clothing and environmental factors influence the physiological responses. However, only environmental factors had any significant influence on the perceptual responses. For performance factors the effects of clothing and environment are less clear. Sprint speed was influenced by clothing factors, but, the reaction time responses were equivocal.

INTERACTION OF THE FOUR SPECIFIC CONDITIONS

Environmental and clothing factors both influenced various physiological, perceptual and performance responses, and although two-way comparisons indicate the general effects of the two factors, they do not succeed in identifying their interaction on the specific demands of batting. Interactional effects are pertinent when examining time course changes of the various responses, specifically to establish which situation and at what stage of activity either of the two factors exerted the principal effect.

The results of comparisons between the four conditions are unequivocal; the physiological responses during cricket activity are elevated by environmental stress as well as protective garments. Analysis of heart rate and sweat rate responses clearly indicate that the environment was the major stressor, with clothing exacerbating these responses, while the major stress factor for skin temperature of sites directly covered appeared to be the protective gear. The perceptual responses suggest that subjects perceived they were working harder, that conditions were warmer and were less comfortable in the High-stress environments, but there was no measurable difference with the additional load imposed by protective clothing.

Based on these findings it is suggested that, in order to reduce the environmental load, strategies and interventions could be employed to assist thermal transfer from the body. Interventions include regulating work rate, removal of padding during intervals and appropriate fluid intake (1 $L.h^{-1}$ or 1.2% BM). Additionally, altering the design of protective gear to improve heat transfer may reduce thermoregulatory strain. Design changes may be beneficial from a physiological standpoint and may also assist in improving sprint times. However, based on these findings, subjects

would not be afforded a reduction in perceptual strain by clothing modifications, no matter how dramatic. A holistic interpretation of the results seems to indicate a more urgent need for the implementation of intervention strategies for participation under High-stress conditions.

CONCLUSIONS

In cricket, as in any athletic environment, health and safety issues and performance enhancement are paramount. An activity where protective clothing is worn, particularly in conjunction with high thermal stress, poses a risk of dehydrating and possibly overheating (Cheung et al., 2000). These situations place an additional demand on physiological and perceptual processes, which can often disrupt performance. Physiological and perceptual strain may induce fatigue. Apart from physical fatigue, which would undoubtedly result in performance detriment, mental fatigue may bring about reduced mental alertness. The combined effects of physical and mental fatigue may reduce motor and psychological skill. Both skills are crucial to superior batting performance (Stretch et al., 2000).

It was clear that High-stress environments and protective clothing influenced physiological and perceptual responses of cricketers. Based on the responses observed it is contended that intense short duration batting activity, likely encountered during one-day participation, imposes a stress on batsmen. The stress is greater when conditions are warmer and protective boundary layers are utilised. The overall thermal stress imposed by the environment and protective gear in this study was not sufficient to impede choice reaction time performances. However, the padding worn did disrupt sprint performance, although it is likely that this is a result of

mechanical factors rather than physiological or perceptual disturbances. It is also contended that for typical one-day batting circumstances, under moderate to hot conditions, dehydration can easily be prevented from becoming a threat to safety or performance by consuming 1 L of fluid per hour.

RECOMMENDATIONS

The following practical recommendations can be drawn from the results obtained in this study:

1) Under conditions of high thermal stress (above 23 °C WBGT) it is advisable that batsmen employ strategies to assist cooling. During the drinks interval padding should be removed and where possible the helmet and gloves should be removed between Overs. If conditions are extremely hot and humid then players should utilise a cooling device such as a cooling vest during the drinks interval. The Australian Cricket team has already used these vests when playing on the Asian sub-continent.
2) Attempts should be made to modify the padding to reduce mechanical disruption and improve sprint times between the wickets. Modifications to protective gear to assist comfort and improve thermal transfer are warranted, but not at the expense of impact protection.
3) A guideline for fluid replacement for batsmen in moderate to hot environmental conditions (21 to 25 °C WBGT) is proposed as 1 $L.h^{-1}$ or 1.2% of body mass in order to prevent significant dehydration at later stages of the game. This guideline is more relevant for players batting early in an innings.
4) Recovery of the players' cardiac system from 7 Overs of intense batting can take up to 15 minutes. This period is longer than the scheduled drinks interval (5 min),

therefore players should aim to regulate work rate to prevent undue fatigue that may result from inadequate recovery.

5) The present regulations of one-day matches make allowance for two drink intervals per innings, although the umpires have the option to utilise more if the environmental conditions are “severe”. Based on recovery HR data and fluid losses, it is suggested that the two scheduled drink intervals (Overs 17 and 34) are suitable for conditions below 21 °C WBGT. However, it is proposed that for optimal performance under environmental stress conditions of above 21 °C WBGT, three intervals (Overs 13, 25, 38) per innings should be mandatory.

With reference to future studies pertaining to the physiological, perceptual and performance responses to batting activity, the following recommendations merit careful consideration:

1) In order to assess the influence of batting duration on various responses it is recommended that similar studies be conducted involving longer batting periods.
2) Another factor that merits consideration is the variable nature of batting. Batting activity is random, intermittent and varies according to the characteristics of play. To determine the effect of different workloads within matches and between match-formats (one-day or first class), similar studies should be conducted involving a variety of work intensities. To obtain truly representative information, where possible, players should be monitored under actual match conditions, not simulations thereof.
3) Further study is required to clarify the effect that extreme environmental stress, similar to conditions experienced on the Asian sub-continent, has on responses while batting.

4) It is imperative that more detailed information on batting responses is obtained, and in order to assess health and safety aspects of various environmental conditions, inclusions of core temperature would add substantially to the understanding of the body's reaction to these demanding situations. The metabolic cost of various batting intensities needs to be identified, particularly in respect of the different formats of the game. In addition to the oxygen consumption requirements of batting, anaerobic indicators such as blood lactate need to be considered. The impact of environment on various aspects of performance, such as concentration and batting skill, and psycho-motor ability, need to be assessed.
5) There is merit in improving the heat dissipating characteristics and reducing ambulatory interference of protective gear. Consequently investigations comparing different brands of protective gear are necessary to determine if specific features of garments offer an advantage over other designs.

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APPENDIX A: GENERAL INFORMATION

Physical Activity Screening Questionnaire

Subject Informed Consent Information Sheet

Subject Consent Form

Instructions to Subjects

Research Protocol

Equipment Check List

PHYSICAL ACTIVITY SCREENING QUESTIONNAIRE

Name: _____
Subject Code: _____

MEDICAL HISTORY

Tick any of the following conditions, diseases or disorders that you have in the past or are presently being treated for, by a physician or health professional.

- ❑ Heart problems
- ❑ Peripheral vascular disorders
- ❑ High/ low blood pressure
- ❑ Epilepsy
- ❑ Anemia
- ❑ Asthma
- ❑ Emphysema
- ❑ Migraine
- ❑ Eye problems
- ❑ Hypoglycemia
- ❑ Diabetes
- ❑ Hyperthyroidism
- ❑ Other (specify) _____

Have you had any recent medical problems? If so give details below.

_____
_____
_____
_____

Are currently suffering from any orthopedic disorder problem? If so briefly describe the problem.

_____
_____
_____
_____

Are there any other concerns medical or otherwise that you feel are worth mentioning?

_____
_____
_____
_____

Please indicate any prescribed or over-the-counter medication you are currently taking or have taken in the last 6 months.

_____
_____
_____
_____

OTHER HABITS

Please tick appropriate box.

Do you smoke?

YES	NO

If yes how many cigarettes per day > 40; 20-40; 10-19; 1-9/ day

> 40	20-40	10-19	1-9

EXERCISE HISTORY

Do you exercise regularly?

YES	NO

How many days per week do you normally spend performing at least 20 minutes of moderate to strenuous exercise?

0	1	2	3	4	5	6	7

Do you experience shortness of breath or chest discomfort with exercise?

YES	NO

Can you jog 4km continuously with a moderate pace without discomfort?

YES	NO

Provide a rough average of the number of organised/scheduled physical activity sessions you participate in during a week. Tick the appropriate block(s) and fill the number of sessions in next to the particular activity.

- ❑ Jogging _____
- ❑ Cycling _____
- ❑ Swimming_____
- ❑ Rugby_____
- ❑ Hockey_____
- ❑ Tennis_____
- ❑ Squash_____
- ❑ Other _____
- ❑ Other _____
- ❑ Other _____
- ❑ Other _____

Department of Human Kinetics and Ergonomics
Rhodes University

Subject Informed Consent Information Sheet

Title of Thesis
Physiological, Perceptual and Performance Responses during Cricket Activity.

General Aims of the Study
The object of this study is to examine cricketers and investigate the effect that hot and cool environmental conditions and protective gear (pads) have on the body's responses to batting activity. At present there is limited information pertaining to physiological, perceptual and performance responses during cricket activity. During the study heart rates, body temperatures, sweat rates, ratings of comfort and perceived exertion, reaction times and sprint times will be collected. These data may provide useful information regarding batting activity in cricket.

Subject Pool
Consists of male cricketers between the ages of 16 and 27 years, to be drawn from school, university, academy and provincial players participating in their respective institution's teams. All subjects should be representatives of at least their 1st team from that particular institution.

A)
There will be three testing sessions.

Testing session 1:
- To explain procedures and objectives of the project
- Sign informed consent form
- To collect basic and baseline data
- Familiarization with instrumentation and equipment
- Habituation of subjects to the work-bout, psycho-physical scales and performance tests
- Assign subjects to test groups

The following basic and baseline (reference) data will be collected at the initial session.
Basic Data: Age
Cricketing experience (years)
Stature
Mass
% Body Fat

Baseline Data: Reference Heart Rate

The duration of the first data collection session will be approximately 3 hours.

Testing sessions 2 and 3 (work-bout sessions):
During these sessions players will be asked to perform several cricket specific batting work-bouts, at which time the research team will monitor certain physiological, perceptual and performance responses. These work-bouts involve 2 clothing and 2 environmental conditions thus 2 x 2 conditions = 4 conditions, with each subject being tested under varying combinations of these conditions. The clothing conditions involve subjects to be tested whilst wearing 1) full batting gear and 2) no batting gear. The environmental conditions will involve a cool and a hot condition.

		Clothing	
		No Gear	Full Gear
Environmental Stress	Low (Day 1)	1	2
	High (Day 2)	3	4

Subjects will only perform two work-bout sessions because both clothing conditions will be tested at each of the two environmental sessions. Each work-bout session will be carried out during either a typically cool or typically warm season so that the hot and cool environmental conditions can be achieved. The months during which cool environmental testing will occur are July-August and the hot environmental testing periods will take place in January-March. Three subjects will be tested on the same day, with the order of the clothing conditions randomised within each environmental stress period.

On each of the test days investigations will commence at 10:00 am; each work-bout will take approximately 30 minutes. There will be a minimum rest period of 2 hours between each work-bout.

The following data will be collected for physiological, perceptual and performance parameters, during the two cricket specific work-bout sessions.

Physiological Data:	Skin Temperatures
	Heart Rate
	Fluid Loss
Psycho-physical Data:	Ratings of Perceived Exertion (RPE)
	Thermal Sensation
	Thermal Comfort
Performance Data:	Agility (20m shuttles) and speed (20m sprint) times
	Reaction time (batting specific choice reaction test)

Heart rate responses will be collected using a polar heart rate monitor. Fluid losses (sweat rates) will be determined by weighing subjects before and after exercise work-bouts. Skin temperature will be recorded from thermal sensors placed at selected sites (4 sites) on the body.

Perceptual parameters will be determined by using various rating scales and a body map. Participants will subjectively provide ratings for the relevant variables.

Performance responses, sprint and agility times will be calculated from timed shuttle sprints performed at certain stages during the work-bout. These timed shuttles are measured using

infrared sensors. Reaction times will be determined using a cricket specific choice reaction time test.

Risks

The risk factors entailed are minimal, and are similar to those encountered during normal cricket participation (batting). All information obtained will be handled in the strictest confidence. Provided that you fill in the physical activity screening form (to be given out at the initial testing session) accurately there is little chance of risk. Players' physiological responses are monitored throughout and the test will be terminated if these are considered excessive.

Benefits

Subjects wishing to obtain feedback will be sent a copy of their results. This should lead to a better awareness of how their body responds and their perception of exertion and thermal comfort during batting activity under various conditions. The overall results will hopefully culminate in an improved understanding of the impact that environmental conditions and protective wear have on the physiological, psycho-physical and performance responses during batting. These data are likely to prove useful in reducing the risk of thermal disorders, identifying optimal fluid replacement practices and rest periods of cricketers and to improve the design of protective gear and clothing. Overall data will also be sent to the respective institutions.

Other

The information in this study is to be used for scientific, clothing design and performance enhancement purposes. You are requested to contact the researchers if you have any queries regarding your data. All the data will be kept and used anonymously. The overall (group) data are to be presented to the manufactures (of the cricket gear) to improve the design of their protective apparel.

SUBJECT CONSENT FORM

I, _____ having been fully informed of the research entitled:

PHYSIOLOGICAL, PERCEPTUAL AND PERFORMANCE RESPONSES DURING CRICKET ACTIVITY

do hereby give my consent to act as a subject in the above named research.

I am fully aware of the procedures involved as well as the potential risks and benefits attendant to my participation as explained to me verbally and in writing. In agreeing to participate in this research I waive any legal recourse against the researchers of Rhodes University, from any and all injuries sustained. This waiver shall be binding upon my heirs and personal representatives. I realise that it is necessary for me to promptly report to the researchers any signs or symptoms indicating any abnormality or distress. I am aware that I may withdraw my consent and may withdraw from participation in the research at any time. I am aware that my anonymity will be protected at all times, and that all the information collected may be used and published for statistical or scientific purposes.

I have read the information sheet accompanying this form and understand it. Any questions that may have occurred to me have been answered to my satisfaction.

SUBJECT (OR LEGAL REPRESENTATIVE):

_____	_____	_____
(Print name)	(Signed)	(Date)

PERSON ADMINISTERING INFORMED CONSENT:

_____	_____	_____
(Print name)	(Signed)	(Date)

WITNESS:

_____	_____	_____
(Print name)	(Signed)	(Date)

INSTRUCTIONS TO SUBJECTS

Day before Testing

- Follow your normal daily eating habits.
- Follow your normal daily pattern of fluid intake.
- Do not consume alcohol 24-48hrs prior to testing.
- Try not to engage in activity that will physically exhaust you 24-48 hours prior to testing. If you do engage in such activity, ensure that you rehydrate by consuming 200-250 ml of water for every 15 minutes of activity.
- Try to get a good nights rest (about 8 hours of sleep).
- Inform the research team if you are ill.

Day of Testing

- Try to eat a good breakfast, suggested meal:
  1 x bowl cereal and milk
  1-2 slices toast with jam
  1-2 portions fruit
  250 ml yoghurt
  250 ml fruit juice
- Make sure that you do not eat within an hour of testing so that your food can digest.
- Drink 400-600 ml water an hour before arriving at the test venue.
- Void urine and faeces before arriving at the test venue.
- Testing starts at 10h00 (10 a.m.) and you should arrive at least 45 min before the testing starts (i.e. 9:15 a.m.).
- Try to eat at least 2 hours prior to arriving at the test venue.

Dress

You are required to bring your own:

- 1-2 x long cricket pants (whites)
- 1-2 x cricket shirts
- Socks
- Underwear
- Trainers (takkies) not spikes
- 1 x box (abdominal guard)
- 1 x pair shorts
- 1 x change of clothes

RESEARCH PROTOCOL

A) Contact schools, university students and clubs

B) Meet with prospective subjects from institutions and supply with information regarding study

C) Inform subjects who are to be included

D) Initial Session (Groups of 4-12 subjects)

8:00	Set-up equipment (see detailed set-up and equipment checklist)
9:00	Explain the day's proceedings
9:15	Administer Physical Activity Screening Questionnaire (PASQ)
9:30	Provide information about:
	The work-bout
	Perceptual scales
	Performance tests
	Rehydration procedures
	Other
9:50	Follow up PASQ and eliminate inappropriate individuals
	Sign informed consent
10:15	Collect Basic and Demographic Data
10:30	Familiarise subjects with instrumentation and equipment
	Collect Reference Heart Rate
10:45	Habituation:
	Work-bout and sprint and agility tests
	Clothing and protective equipment
	Perceptual scales
	Cricket specific reaction test
11:30	Completed

Initial Session – Detailed Set-Up

a) Tennis Court
- Lines on Court
- Laptop and Cable
- Desks
- Perceptual Scales
- Sprint & Agility and Reaction Timer
  - Mats
  - Console
  - Assorted Leads
  - LED, stands and barriers
  - Power Cables
- Bowling Machine & balls & power cables

b) Laboratory
- General Data Sheets
- Pens
- Teledo Scale
- BIA
- Stadiometer
- Polar HR monitors & electrode gel
- HR monitor interface unit
- Data Logger
- Skin temperature Sensors
- Pads & Gear
- Batting specific reaction timer

c) Meeting Room
- Individual Files
  - Informed Consent
  - Information
    - Pre-test instructions
    - Perceptual Scales
- Pens

Initial Session – Equipment Test

a) Laboratory
- Clear previous data (HR monitors)
- BIA Self-test
- Check reaction timer

b) Tennis Court
- Set bowling machine (Line and Length)
- Check sprint timer and LED set-up

E) Testing Sessions (2-3)

7:45	Set-up and check equipment (see detailed procedures and equipment checklist)
8:45	Monitor environmental conditions
9:00	Arrival of subjects
9:10	Euhydration Procedure
9:20	Pre-test procedures during each work-bout for each subject (see detailed procedures)
10:00	Start work-bout and collection procedures *Collection Procedures during work-bout
10:25	Post-test procedures (see detailed procedures)
10:40	REPEAT until each subject has completed their first trial
12:30	Lunch
13:30	Continue with subjects' second trials until all are complete

Testing Sessions Set Up – Detailed Procedures

a) Tennis Court

- Lines on Court
- Laptop and Cable
- Desks
- Perceptual scales
- Sprint & Agility Timer
  - Mats
  - Console
  - Assorted leads
  - LED, stands and barriers
  - Power cables
- Bowling machine & balls & power cables
- Stopwatch and watch

b) Laboratory

- Work-bout data sheets
- Reaction timer sequence sheets
- Clipboards
- Pens
- Teledo scale
- BIA
- Stadiometer
- Polar HR monitors & water
- Data logger
- Data logger interface
- HR monitor interface
- Skin temperature sensors
- Set-up reaction timer
- Pads & gear
- Cleaning materials

c) Test Equipment Test

i) Anthropometry Room

- Clear Previous Data (HR monitors and data logger)
- BIA Self-test
- Check reaction timer

ii) Tennis Court

- Set-up bowling machine (Line and Length)
- Set-up sprint timer and LED's

d) Pre-test

9:10 Euhydration procedure
- Consumes 500ml water

9:20 Pre-test procedures prior to each work-bout for each subject:
- Shave skin and mark locations for skin temperature sensors
- BIA analysis
- Fit HR monitor
- Sit for 3-5 min before recording reference HR
- Weigh subjects (underwear only), clothing and gear
- Fit instrumentation, clothing and/or gear
- Move to test area (tennis court)
- Monitor environmental conditions
- Familiarise and warm-up

10:00 Start work-bout and collection procedures
- Fill in player's data on computer (sprint and agility)
- Start sprint and agility device
- Record anticipatory HR
- Start stopwatch
- Deliver 3 balls
- Record time after sprint
- Confirm sprint timer is error free
- Deliver 3 balls
- Over complete
- Record time
- Confirm sprint timer is error free
- Record perceptual responses (RPE, thermal sensation and comfort)
- Repeat for 6 more overs
- Work-bout ends
- Stop sprint and agility timer

e) Post-test

10:25 Work-bout completed
- Monitor environmental conditions
- Return to laboratory
- Perform reaction time test
  - Perform practice trials
  - Start sequence
- Remove and clean temperature sensors
- Remove clothing and gear
- Weigh subject
- Start preparing next subject
- First subject replaces clothes and moves back to testing area, continue to monitor HR for 40 min.
- If equipment is not in use then put out to dry
- When back at test area subjects can consume fluid (ad libitum)

REPEAT FOR NEXT SUBJECT

EQUIPMENT CHECKLIST

Administration

- ❑ Initial contact letter to institutions
- ❑ Physical Activity Screening Questionnaire

Initial Session

- ❑ Subject informed consent information sheet
- ❑ Subject consent forms
- ❑ General data collection sheets
- ❑ Instructions for RPE, thermal sensation and thermal comfort
- ❑ Perceptual scales
- ❑ Pre-test day instruction sheets
- ❑ Files for sheets

Testing sessions

- ❑ 3 x Data collection sheets

Stationary

- ❑ Masking tape for tennis court
- ❑ 3 x Clipboards
- ❑ Pens/ pencils
- ❑ Scissors
- ❑ Permanent marker pens (electrode placement)

Computer Equipment

- ❑ Laptop computer (field collection of sprint times)
- ❑ PC for downloading from data logger
- ❑ Interface for data logger and HR monitor

Data Collection Equipment

Initial session

Morphological variables

- ❑ Teledo scale
- ❑ Lipocare BIA
- ❑ Holtain stadiometer

Physiological variables

- ❑ 3 x Polar HR receivers, straps, electrodes and electrode gel
- ❑ 1 x Smart Reader Plus™ data logger and holder
- ❑ 4 x Skin temperature sensors
- ❑ Teledo scale

Perceptual Variables

- ❑ RPE scale
- ❑ Thermal sensation scale
- ❑ Thermal comfort scale

Performance Variables

- Sprint/ agility timer, mats and LED's
- Screens (4 x tables)
- Batting specific reaction timer

Testing sessions

Physiological Variables

- 3 x Polar HR receivers, straps, electrodes and electrode gel
- 1 x ACR Smart Reader Plus^{TM} data logger and holder
- 4 x Skin temperature sensors, tape and razor
- Lipocare BIA
- Teledo scale

Perceptual Variables

- RPE scale
- Thermal sensation scale
- Thermal comfort scale

Environmental Variables

- Stevenson Screen
- Globe Thermometer
- Mason's hygrometer
- Temperature and RH sensor
- Distilled water

Performance Variables

- Sprint/ agility timer, mats and LED's
- Batting specific reaction timer

Medical Equipment

- Milton disinfectant
- Bucket
- Cloths
- Benzene (cleaning adhesive tape from electrodes)
- Cleaning ethanol (disinfectant)
- Soap water

Clothing and Protective Gear

- Helmet x 1
- Bat x 1
- Gloves x 2 pair
- Pads x 1 standard pair
- Thigh guard x 1 pair
- Inner thigh guard x 1 pair
- Abdominal protector x 3

Collection Area (Tennis Court)

- Power cable extension and adaptors
- 2 x tables
- Shade cloth or umbrella
- Partitions to shelter from wind and radiation

Miscellaneous

- Cooler box
- Meals and fluid for subjects and researchers
- Watch
- 2 x chairs

- Ball machine
- Balls (indoor) x 6

- Testing roster
- Elastic bands/ twist ties (electrodes)

APPENDIX B: DATA COLLECTION

General Data Sheet

Data Collection Sheet

Sprint Data Collection Sheet

RPE Scale

Thermal Sensation and Comfort Scales

Instructions to Subjects Regarding Perceptual Scales

GENERAL DATA

CODE:

DATE:

Name: _____

Date of Birth (yy\ mm\ dd): _____ Age at time of testing: _____

Home Language: _____

CRICKET SPECIFIC DATA

Primary function in team (Tick appropriate box):

Batsman	Bowler	All-rounder	Keeper

Current Team Represented: _____

Highest team represented at school and date: _____

Provincial or national representation (where applicable) and date – state whether

at School or Senior Level (where applicable): _____

_____

Years of cricketing experience: _____

Research use only

ANTHROPOMETRICAL DATA **Resting Heart Rate _____** $b.min^{-1}$

Mass: _____kg

Stature: _____mm

Bioelectrical Impedance Analysis

Fat Mass: _____kg

Body Fat: _____%

Lean Body Mass: _____kg

Body Mass Index: _____$kg.m^2$

DATA COLLECTION SHEET

Name:

Date: **HR Monitor #:**

Subject Code:	**Condition Code:**

Test Day **1** **2**

Time:

ANTHROPOMETRIC DATA

Stature:
Mass:

Fat Mass	Body Fat	Lean Body Mass	Body Mass Index

ENVIRONMENTAL DATA

	Time	T_A	RH	T_{VWB}	T_{NWB}	T_G	MDI	WBGT
Before Work-Bout								
After Work-Bout								

FLUID BALANCE

	Pre	Post
Time		

Subject Mass		

Change:

REFERENCE DATA

Time	**Physiological Response**
	HR ($b.min^{-1}$)

PHYSIOLOGICAL AND PERCEPTUAL RESPONSES

Anticipatory HR: _____

Work-bout Data

Over	Activity & time			HR	RPE	Thermal Sensation	Thermal Comfort
	End of shuttle	Time	Stop Watch				
Start							
1							
2							
3							
4							
5							
6							
7							
Finish							

NOTES

_____

_____

_____

_____

_____

SPRINT DATA COLLECTION SHEET

Name:

Date:

Code: **File:**

	Trial #	Sprint 1	Turn	Sprint 2	Overall
	1				
	2				
	3				
	4				
	5				
	6				
	7				
	8				
	9				
	10				
	11				
	12				
	13				
	14				
	15				
	16				
	17				
	18				
	Slow				
	Fast				
	Mean				
	S.D.				

RATING OF PERCIEVED EXERTION (BORG)	
6	
7	VERY, VERY LIGHT
8	
9	VERY LIGHT
10	
11	FAIRLY LIGHT
12	
13	SOMEWHAT HARD
14	
15	HARD
16	
17	VERY HARD
18	
19	VERY, VERY HARD
20	

ASHRAE SENSATION SCALE	
Hot	7
Warm	6
Slightly warm	5
Neutral	4
Slightly cool	3
Cool	2
Cold	1

THERMAL COMFORT RATING

Indicate if you would:

1 = Be more comfortable if it was cooler
2 = Be more comfortable if it was warmer
3 = Prefer no change in temperature

INSTRUCTIONS TO SUBJECTS FOR RPE

You are now going to take part in a work test. You are going to be performing a simulated batting situation whereby you will face deliveries and perform shuttle runs at set intervals throughout the test while we measure various physiological and psychological functions. During the test, we want you to try and estimate how hard the activity is; that is, we want you to identify the level of exertion that you feel. You will be asked to point to a number on the scale presented, which corresponds to your rating of perceived exertion. The rating will be a general, overall rating pertaining to the feelings and sensations of the body's muscular and cardiovascular system.

Try to estimate as honestly and as objectively as possible. Do not underestimate the degree of exertion you feel, but do not overestimate it either. Try to estimate it as accurately as possible. You will be requested to give ratings of perceived exertion after every second shuttle run during the test. When you are asked to rate your work, you should do so by giving the numerical value, which indicates your evaluation of your overall perceived exertion at that moment. A rating of six (6) corresponds with feelings of exertion while standing quietly, whereas a rating of twenty (20) reflects maximal exertion.

INSTRUCTIONS TO SUBJECTS FOR THERMAL SENSATION AND THERMAL COMFORT RATINGS

You are now going to take part in a work test. You are going to be performing a simulated batting situation whereby you will face deliveries and perform shuttle runs at set intervals throughout the test, while we measure various physiological and psychological functions. During the test we want to try and determine your sensation of the thermal environment, how the temperature of the environment feels to you, and your comfort level relative to the temperature of this environment whilst performing the batting activity. You will be asked to point to a number on the scale presented, which corresponds to your rating of thermal sensation; the rating describes if the environment is hot, neutral or cold. You will then be asked to point to a second scale and indicate how your current level of comfort may be improved, if at all.

Try to estimate as honestly and objectively as possible. Do not overestimate the temperature of the environment, but do not underestimate it either. Try to estimate as accurately as possible how your level of comfort may be improved. You will be requested to give ratings of thermal sensation and thermal comfort after every second shuttle run during the test. When you are asked to rate how the temperature feels to you in this environment, you should do so by giving a numerical value. This rating indicates the thermal sensation experienced; a rating of seven (7) indicates that you are hot, whereas a rating of one (1) that you are cold and four (4) that the environment is neutral (neither hot nor cold). When asked to rate your comfort in this environment you will be asked if you are comfortable in the environment; if you are then you indicate

that you would prefer no change in the temperature. However, if the temperature makes you feel uncomfortable, you must say if you would prefer conditions to be warmer or cooler.

APPENDIX C: RESULTS

Sample Calculations

Polar Heart Rate Print Out

SAMPLE CALCULATIONS

Body Surface Area:

$$BSA\ (m^2) = 0.202\ (Body\ Mass^{0.425} \times Stature^{0.725})$$

$$= 0.202\ [(77kg)^{0.425} \times (182.5\ cm)^{0.725}]$$

$$= 1.98\ m^2$$

Body Mass Index:

$$BMI\ (kg.m^{-2}) = \frac{Body\ Mass}{Stature^2}$$

$$= \frac{77\ kg}{(1.825\ m)^2}$$

$$= 23.1\ kg.m^{-2}$$

Reciprocal Ponderal Index:

$$RPI\ (mm.\sqrt[3]{kg^{-1}}) = \frac{Stature}{\sqrt[3]{Body\ Mass}} \times 1000\ mm.m^{-1}$$

$$= \frac{1.825\ m}{4.254\ \sqrt[3]{kg}} \times 1000\ mm.m^{-1}$$

$$= 429\ mm.\sqrt[3]{kg^{-1}}$$

Mean Skin Temperature:

MST (°C) = 0.50 Chest + 0.35 Arm + 0.14 Shin

MST (°C) = 0.50 (32. 14 °C) + 0.35 (36.95 °C) + 0.14 (37.13 °C)

MST (°C) = 34.57 °C

Absolute Sweat Loss:

$SL\ (L) = [Body\ Mass\ before\ activity\ (kg) – Body\ Mass\ after\ activity\ (kg)] / g.ml^{-1}$

$SL\ (L) = (76.18\ kg – 75.6\ kg) / g.ml^{-1}$

$SL\ (L) = 0.58\ kg / g.ml^{-1}$

$SL\ (L) = 580\ g / g.ml^{-1}$

$SL\ (L) = 0.580\ L$

Relative Sweat Loss:

$SL_{REL}\ (\%\ BM) = [SL\ (L)/ Body\ Mass\ before\ (kg)] \times 100$

$SL_{REL}\ (\%\ BM) = (0.58\ L / 76.18\ kg) \times 100$

$SL_{REL}\ (\%\ BM) = 0.76\ L.kg^{-1}$

$SL_{REL}\ (\%\ BM) = 0.76\ \%\ BM$

Since 1 kg is equivalent to 1 L.

Absolute Rate of Sweat Loss:

$SL_{RATE}\ (L.h^{-1}) = [SL\ (L)/ Duration\ of\ work\text{-}bout\ (min)] \times 60\ min.h^{-1}$

$SL_{RATE}\ (L.h^{-1}) = (0.58\ L / 36\ min) \times 60\ min.h^{-1}$

$SL_{RATE}\ (L.h^{-1}) = (0.0161\ L.min^{-1}) \times 60\ min.h^{-1}$

$SL_{RATE}\ (L.h^{-1}) = 0.97\ L.h^{-1}$

Relative Sweat Rate:

$SL_{RELRATE}\ (\%\ BM.h^{-1}) = [SL_{REL}\ (\%\ BM)/ work\text{-}bout\ duration\ (min)] \times 60\ min.h^{-1}$

$SL_{RELRATE}\ (\%\ BM.h^{-1}) = (0.76\ \%\ BM / 36\ min) \times 60\ min.h^{-1}$

$SL_{RELRATE}\ (\%\ BM.h^{-1}) = (0.021\ \%\ BM.min^{-1}) \times 60\ min.h^{-1}$

$SL_{RELRATE}\ (\%\ BM.h^{-1}) = 1.27\ \%\ BM.h^{-1}$

Wet Bulb Globe Temperature:

$WBGT\ (C°) = 0.7 \times T_{NW} + 0.2 \times T_G + 0.1 \times T_A$

$WBGT\ (C°) = (0.7 \times 16.25\ °C) + (0.2 \times 37\ °C) + (0.1 \times 25\ °C)$

$WBGT\ (C°) = 21.28\ °C$

Modified Discomfort Index:

$MDI\ (C°) = 0.3T_A + 0.75T_{NW}$

$MDI\ (C°) = (0.3 \times 25\ °C) + (0.75 \times 16.25\ °C)$

$MDI\ (C°) = 19.69\ °C$

POLAR HEART RATE PRINT OUT

Curve

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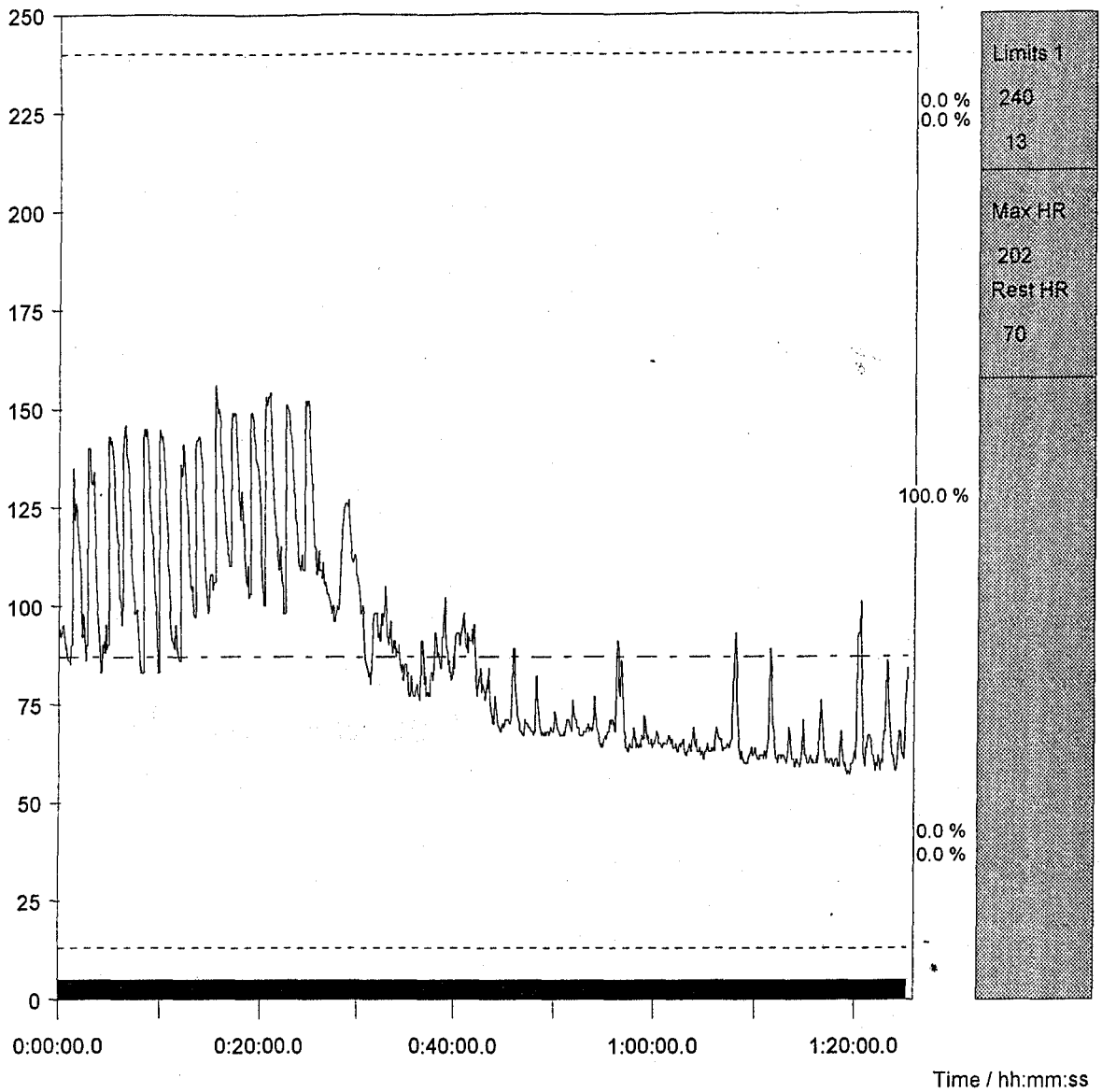
HR / bpm

File Summary (%)



HR: 94
Time: 0:00:00.0

Person	Joe Average	**Date**	2001/07/05	**Average**	87 bpm	**Recovery**	10 bpm
Exercise		**Time**	12:21:04.0 PM	Duration of exercise: 1:25:23.4			
Note				Selected period: 0:00:00.0 - 1:25:20.0 (1:25:2			