

# THERMOREGULATION DURING SOCCER SPECIFIC INTERMITTENT EXERCISE: THE EFFECTS OF CLOTHING AND ENVIRONMENT

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A thesis submitted in partial fulfilment of the  
requirements of Liverpool John Moores University for  
the degree of Doctor of Philosophy

August 2000

## ABSTRACT

Team sports such as soccer follow an intermittent pattern of exercise, which is known to place greater demands on thermoregulation than continuous exercise of a similar intensity. Time to exhaustion has been shown to be dependent upon environmental temperature, while clothing is known to create a microenvironment at the surface of the skin. The aim of this thesis was to determine the thermoregulatory response to soccer-specific intermittent exercise during different conditions of clothing and environment.

The thermal and physiological responses of the feet to continuous and soccer-specific intermittent exercise were evaluated. Intermittent exercise was found to induce an increase in foot skin temperature of a greater magnitude than during continuous exercise of the same overall intensity. The findings indicate that the foot maintains an altered thermoregulatory response not evident elsewhere on the human body.

The localised and whole-body physiological and thermal responses to soccer footwear were examined during soccer-specific intermittent exercise. Soccer footwear does not have a significantly detrimental effect on physiological responses compared to training shoes. Nevertheless, there was evidence of increased thermal strain when wearing the soccer boot, which may become significant in a hot environment.

Similarly, the localised and whole-body physiological and thermal responses of the hands were evaluated when wearing goalkeeping gloves during simulated goalkeeper activity. Goalkeepers' gloves restrict heat loss from the hand and in order to alleviate this problem, phase control materials (PCM's) have been developed to reduce heat load and maintain a comfortable skin temperature. All sites of skin measurement, except mean body skin temperature, showed uniformly that a PCM glove caused a greater increase in skin temperature than a glove with normal foam material. Therefore, the particular specification of PCM used in this study promoted heat gain rather than the intended heat loss and was therefore inappropriate to enhance thermal comfort when used in a goalkeeper's glove.

The effects of three different environmental conditions (10°C, 20°C and 30°C) on soccer-specific intermittent exercise were examined. Results showed that the physiological strain associated with soccer-specific intermittent exercise is greatest in the heat (30°C) with parameters such as heart rate, mean skin temperature, rating of perceived exertion, thermal perception, change in body mass and skin blood flow all lowest during exercise in the cool. Exercise in the cool condition (10°C) may be the optimal environment for performance of soccer-specific intermittent exercise.

A significant relationship was found between core temperature and prolactin (marker of brain serotonin activity) suggesting that central serotonergic mechanisms of fatigue may play a role in exercise performance during soccer-specific intermittent activity performed in the heat.

The effects of traditional soccer fabrics and technical fabrics on the physiological and thermoregulatory responses to soccer-specific intermittent exercise were evaluated. Analysis revealed that slight differences between traditional and technical clothing ensembles in physiological parameters, such as heart rate, mean skin temperature, body mass loss and rating of perceived exertion, were not significant. Therefore, wearing technical fabric clothing gives no particular benefit over a traditional fabric ensemble.



The lack of differences between clothing materials lead to the conclusion that an elite soccer team competing under extremes of temperature in international climates would be best advised to concentrate on proper acclimatisation, nutrition and fluid replacement strategies prior to competition than on the specifics of clothing design.

## ACKNOWLEDGEMENTS

I wish to thank the following people whose help and support have been invaluable in the creation of this thesis:

Firstly, I wish to extend my deepest gratitude to Dr Tim Cable for the trusted guidance he has given me as my Director of Studies, for always finding time and for always giving sound advice. Sincere thanks must also go to Professor Tom Reilly for his supervision throughout this research project and for giving me the initial opportunity and inspiration.

Without the enthusiasm and willingness of the experiment participants there would be no data and no thesis, so a huge thank you must go to all who gave their time and energy in taking part. A special thank you to David Low, David Jackson and Robert Ward, who also assisted in the collection of data.

My colleagues in The Centre for Sport and Exercise Sciences deserve special thanks as all have contributed in some way. Many thanks go to the technical staff, in particular the assistance of Helen Cox in the biochemistry laboratory. The assistance of Dr Greg Atkinson has been invaluable in all matters statistical. The support, encouragement and friendship of the post-graduates have been second to none, but Ginny Coyles, Judith Smith and Sue Taylor stand out in particular.

Thanks must go to my friends and family who, sensibly, have nothing to do with PhD's and provide those much needed reality checks. In particular; Kate Burtoft, Josie Wilson, and Ruth Ashton.

Last but certainly by no means least, Mum and Dad, thanks for always supporting me and never doubting that I would achieve my goals.



## DECLARATION

I declare that the work presented in this thesis is entirely my own, with the exception of the following:

1. The study described in Chapter 5 represents work conducted by the Author, assisted by R. A. Ward. The Author was responsible for the supervision of R. A. Ward during this, his Diploma project work and for the analysis of all data presented in this chapter.
2. The study described in Chapter 6 represents work conducted by the Author, assisted by D. M. Jackson and D.A. Low. The Author was responsible for the supervision of D. M. Jackson and D.A. Low during this, their B.Sc. Dissertation work and for the analysis of all data presented in this chapter.
3. The serum prolactin samples in Chapters 6 and 7 were analysed at the Royal Liverpool University Hospital by the staff at the Department of Clinical Chemistry.

The results of this thesis have been presented as internal reports to Umbro International and have not been used by the Author to obtain other qualifications.

## LIST OF PUBLICATIONS

The following publications have resulted from the work presented in this thesis and copies are included in Appendix 1:

Purvis, A.J. and Cable, N.T. (1999). Effects of exercise mode on foot skin temperature. *Journal of Sports Sciences*, **17**, 816 (abstract).

Purvis, A.J. and Cable, N.T. (2000). The effects of phase control materials on hand skin temperature within gloves of soccer goalkeepers. *Ergonomics*, **43**, 1480-1488.

Purvis, A.J., Jackson, D.M., Low, D.A. and Cable, N.T. (2000). Responses to soccer-specific intermittent exercise during different environmental conditions. *Journal of Sports Sciences*, (abstract, in press).



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## CHAPTER 1. INTRODUCTION

# 1. INTRODUCTION

## 1.1 BACKGROUND

Nowadays much emphasis is placed upon enhancing performance of the elite athlete. This enhancement is often achieved by attempting to delay the onset of fatigue. One factor implicated in the development of fatigue is core temperature, high values being associated with premature cessation of exercise. Galloway and Maughan (1997) reported a "clear effect of temperature on exercise capacity which appears to follow an inverted U relationship". They comprehensively examined the effect of four different ambient temperatures (4°C, 11°C, 21°C, and 31°C) on physiological parameters during exercise till exhaustion. Significant effects of ambient temperature were observed on oxygen consumption, ventilation, heart rate, core temperature, sweat rate, rating of perceived exertion and time to exhaustion. The study is particularly interesting as the intensity of exercise, steady state at 70%  $\dot{V}O_{2\max}$ , is similar to that reported for soccer match-play (Reilly, 1990). Morris *et al.* (1998) studied the effects of a hot environment on the performance of intermittent, high-intensity shuttle running and also reported reduced performance in a hot environment, associating fatigue with high core temperature. Although these studies infer that physiological strain is elevated and performance decreased in adverse conditions, no studies have examined the impact of environmental change and clothing on the response to soccer-specific intermittent exercise. In an attempt to improve thermal comfort and facilitate heat loss from the body as body temperature rises, a number of commercial organisations have developed new clothing fabrics. This development is particularly true in the soccer industry, but it remains unclear whether these products actually achieve their aims.

Analysis of soccer match-play in adverse environments is particularly relevant when international competitions, such as the soccer World Cup, are often held in hot climates. Examples of this are the 1990 World Cup in Italy, 1994 in the United States of America and the forth-coming 2002 World Cup to be held jointly in Japan and Korea. Match-play in cooler environments does not pose the same threats to the human thermoregulatory system, although the physiological demands of such environments have not been quantified specifically in soccer activity.

## ***1.2 INTRODUCTION TO RESEARCH***

The analysis of the demands of soccer in different environmental and clothing conditions will be achieved by the use of laboratory research. Laboratory simulations of soccer specific activity will allow for realistic replication of the expected physiological responses to soccer match-play. Little information is available regarding the thermoregulatory responses to clothing and environmental factors during such soccer activity.

It is the purpose of this thesis to quantify the impact of environmental and clothing variables during soccer specific intermittent exercise. The thesis is structured with studies in which the thermoregulatory responses of the periphery are evaluated in Chapter 4 while whole-body responses are quantified with reference to clothing in Chapter 5, environmental conditions in Chapter 6 and a combination of clothing and environment variables examined in Chapter 7.

## ***1.3 AIMS AND OBJECTIVES***

The thermoregulatory responses during soccer specific intermittent exercise will be defined with special reference to the effects of clothing and environment through the fulfilment of the following aims: -



Aim 1: Investigate the effects of exercise mode on thermal responses of the whole-body and the feet.

Aim 2: Investigate the effects of exercise mode and soccer equipment materials on thermal responses of the whole-body and the feet.

Aim 3: Investigate the effects of exercise and soccer equipment materials on thermal responses of the whole-body and the hands.

Aim 4: Examine the effects of clothing layers on physiological, metabolic, whole-body and localised thermal responses during soccer specific intermittent exercise in a neutral environment.

Aim 5: Examine whole-body physiological and metabolic responses to soccer specific intermittent exercise in neutral, cool and warm environments.

Aim 6: Examine the effects of technical sportswear materials on whole-body thermal, physiological and metabolic responses during soccer specific intermittent exercise in a warm environment.

The realisation of the above aims will be accomplished by the following objectives: -

Objective 1: Evaluation of the thermal and physiological responses of the feet to steady-state exercise and soccer specific intermittent exercise will be conducted.

Objective 2: The localised thermal responses of feet and whole-body physiological responses to soccer footwear materials will be evaluated using laboratory simulations of soccer match-play.

- Objective 3: The localised thermal responses of the hands and whole-body physiological responses to soccer goalkeeping glove materials will be evaluated using a goalkeeper specific simulation of soccer match-play.
- Objective 4: The effects of clothing layers on the physiological and thermoregulatory responses to soccer specific intermittent exercise in a neutral environment will be evaluated in a controlled environmental chamber.
- Objective 5: The effects of different environmental conditions will be evaluated during soccer specific intermittent exercise in a controlled environmental chamber.
- Objective 6: The effects of traditional fabrics vs. technical fabrics on the physiological and thermoregulatory responses to soccer specific intermittent exercise in a warm environment will be evaluated in a controlled environmental chamber.

## CHAPTER 2. REVIEW OF LITERATURE



## 2. REVIEW OF LITERATURE

*The aim in this section is to provide a review of the current literature regarding the physiological and metabolic demands of clothing and environmental conditions with special reference to soccer specific intermittent exercise.*

### 2.1 HUMAN THERMOREGULATION

The thermal environment is comprised of four basic parameters: air temperature, radiant temperature, humidity and air movement. These variables are then combined with human activity and the clothing worn to total six elements which constitute the dynamic thermal environment within which a human interacts (Fanger, 1970; Parsons, 1993; ISO 113999, 1995). Thermoregulation is the regulation and maintenance of body temperature including heat production, heat transfer, heat conservation, temperature sensation and control mechanisms. When heat transfer is not balanced, heat gain or heat loss results, which is reflected in physiological responses. Imbalances in heat transfer may be due to environmental, physiological, behavioural, pathological and pharmacological factors.

In contrast to the large range of temperatures found in the global environment (-90°C to +60°C), the human body is regulated within a very narrow range normally between 35°C to 40°C, but temperatures up to 41°C during exercise in hot conditions may be tolerated for short periods of time (Stolwijk, 1977). The accurate regulation of internal temperature is necessary to maintain normal body function. Above 44°C proteins within the body begin to denature, but symptoms of hyperthermia are observed at much lower temperatures as mechanisms are instigated to protect the body. Thermoreceptors are located throughout the body, in the skin, core tissues and the central nervous system, and all have neural inputs to the hypothalamus in the brain, which is understood to be the

central controller of temperature regulation (BOHS, 1990). The temperature of the blood passing through the hypothalamus is also an important factor in regulation of body temperature. The hypothalamus integrates the inputs from the thermoreceptors allowing the maintenance of a stable core temperature.

The processes that occur during exercise are antihomeostatic and can impose large stresses on regulatory systems of the human body. During exercise the metabolic rate is elevated above resting levels by as much as 15 times to provide the necessary energy for muscle contractions (Sawka and Wenger, 1988). This higher metabolism produces heat, which must be dispersed to the environment in order to maintain a healthy core temperature.

### 2.1.1 Thermal Balance

In this section, the quantitative conditions for thermal balance are examined. It is useful to understand the equations of heat balance and the influence of the individual components. The conceptual heat balance equation describes the thermodynamics between the body and the environment and is the most basic form of the heat balance equation. The following equations are presented in much of the literature concerning the biophysics of heat transfer (Fanger, 1970; Parsons, 1993; Thornton and Nair, 2000).

**Equation 2.1.** Conceptual heat balance equation.

$$M - W = \pm R \pm C \pm K - E + S$$

Where all terms are in units of  $\text{W m}^{-2}$ ,

- $M$  = rate of metabolic heat production
- $W$  = rate of mechanical work (output)
- $R$  = rate of radiative heat loss
- $C$  = rate of convective heat loss



$K$	=	rate of conductive heat loss
$E$	=	rate of evaporative heat loss
$S$	=	rate of heat storage

The conceptual heat balance equation may be further refined to provide separate values for heat transfer at the skin and via respiration:

**Equation 2.2.** Refined heat balance equation.

$$M - W = Q_{sk} + Q_{res} = (C + R + E_{sk}) + (C_{res} + E_{res})$$

Where all terms are in units of  $\text{W m}^{-2}$ ;

$M$	=	metabolic heat production
$W$	=	rate of mechanical work
$Q_{res}$	=	rate of total heat loss through respiration
$Q_{sk}$	=	total rate of heat loss from the skin
$C_{res}$	=	rate of convective heat loss from respiration
$E_{res}$	=	rate of evaporative heat loss from respiration
$C$	=	rate of convective heat loss from the skin
$R$	=	rate of radiative heat loss from the skin
$E_{sk}$	=	rate of total evaporative heat loss from the skin

The rate of evaporative heat loss from the skin ( $E_{sk}$ ) is of the most important parameter of heat loss during exercise and should be considered in terms of sweat evaporation and moisture diffusion.

**Equation 2.3.** Total evaporative heat loss from the skin.

$$E_{sk} = E_{rsw} + E_{dif}$$

Where all terms are in units of  $\text{W m}^{-2}$ ;

$E_{rsw}$	=	rate of evaporative heat loss from the skin through sweating
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$E_{dif}$  = rate of evaporative heat loss from the skin through moisture diffusion

Moisture diffusing through the skin represents insensible water loss and is not subject to thermoregulatory control. The rate of diffusion is dependent upon the pressure gradient between the partial pressure of water vapour at the skin ( $P_{sk}$ ) and the partial pressure of water vapour in the surrounding ambient air ( $P_a$ ). The rate of moisture diffusion is also dependent upon the surface area of the individual.

**Equation 2.4.** Heat loss by water vapour diffusion through the skin.

$$E_{dif} = \lambda m A_{Du} (P_{sk} - P_a)$$

Where;

$E_{dif}$  = rate of heat loss from the skin through moisture diffusion ( $\text{W m}^{-2}$ )  
 $\lambda$  = heat of vaporisation of water (at 35°C), ( $\text{W m}^{-2}$ )  
 $m$  = permeation coefficient of the skin  
 $A_{Du}$  = Dubois (1916) surface area, ( $\text{m}^2$ )  
 $P_{sk}$  = water vapour pressure at the skin (often assumed to be saturated,  $P_s$ ), ( $\text{kPa}$ )  
 $P_a$  = water vapour pressure in ambient air, ( $\text{kPa}$ )

The evaporative heat loss from the skin ( $E_{sk}$ ) takes into consideration the clothing worn and is defined as follows:

**Equation 2.5.** Heat loss by water evaporation from the skin.

$$E_{sk} = \frac{w(P_{sk} - P_a)}{\left[ R_{e,cl} + \frac{1}{f_{cl} h_e} \right]}$$

Where;

- $E_{sk}$  = rate of evaporative heat loss from the skin through moisture diffusion ( $\text{W m}^{-2}$ )  
 $w$  = skin wettedness, the fraction of wetted skin (ND)  
 $P_{sk}$  = water vapour pressure at the skin (often assumed to be saturated,  $P_s$ ), ( $\text{kPa}$ )  
 $P_a$  = water vapour pressure in ambient air, ( $\text{kPa}$ )  
 $R_{e,cl}$  = evaporative heat transfer resistance of clothing surface, ( $\text{m}^{-2} \text{ kPa W}^{-1}$ )  
 $h_e$  = convection evaporative heat transfer coefficient at the clothing surface, ( $\text{m}^{-2} \text{ kPa W}^{-1}$ ). Calculated using the Lewis relation  $h_e = LR h_c$   
 $f_{cl}$  = clothing area factor = ratio of the surface area of the clothed body to the surface area of the nude body

Stemming from the heat balance equation is the quantification of thermal stress in a hot environment by calculation of required sweat rate ( $SW_{req}$ ). Required sweat rate (in  $\text{W m}^{-2}$ ) is a function of required evaporative rate ( $E_{req}$ ) and required skin wettedness ( $r_{req}$ ) and predicts the sweat production necessary to maintain thermal balance (heat storage = zero). It is used to determine the maximum allowable exposure time to heat stress in an industrial setting (ISO 7933, 1989).

For further derived equations allowing more detailed examination of the physics of heat transfer the reader is referred to the following publications (Fanger, 1970; McIntyre, 1980; Parsons, 1993; Thornton and Nair, 2000).

Therefore, there are three main areas of consideration for heat balance: these are metabolic heat production within the human body, heat transfer at the skin and heat transfer due to respiration. The heat loss due to respiration during typical exercise have been quantified as in the region of  $2 - 5 \text{ g min}^{-1}$  (Mitchell *et al.*, 1972) as when air is inhaled it is warmed and saturated with water vapour before being exhaled. This causes heat to be lost due to respiration by convection and evaporative heat transfer.



### 2.1.2 Exercise and Core Temperature

The most fundamental measure in thermoregulatory research is the measurement of core temperature. There is no exact core temperature as the temperature of deep tissue varies between locations within the human body, although all locations of core temperature are closely comparable. The most common sites of core temperature measurement are rectum, oesophagus, auditory meatus and tympanum with the rectal temperature possibly being the single most used site for measurement in physiological research. Rectal temperature is characteristically higher than other core temperature sites and is slow to respond to changes in thermal demand due to low blood flow in the rectum. The rectal thermometer is usually placed between 5 and 20 cm beyond the anal sphincter, as the temperature is uniform within this region. Core temperature afferent input to the hypothalamus is dominant in activating physiological responses to maintain a steady thermal state (Bulcao *et al.*, 2000).

It is well researched and understood that core temperature increases during exercise (Gleeson, 1998). This increase is due to a proportion of metabolic heat production from the active skeletal muscle being stored and increasing body temperature. This effect occurs during prolonged exercise (MacDougall *et al.*, 1974) and during exercise in uncompensable hot environments (González-Alonso *et al.*, 1999).

Core temperature rises to dangerous levels if heat loss mechanisms do not activate to offset the rapid increase in metabolic heat production. The magnitude of increase in core temperature is much greater at high intensity workloads above 75%  $\dot{V}O_2$  max, such as during soccer match-play (Reilly, 1990; 1996a; Bangsbo, 1994b), placing greater necessity on mechanisms of heat loss to prevent soccer performance being compromised. The physiological control of heat loss is achieved entirely by the autonomic nervous



system and includes the control of metabolism, blood flow (vasomotor control) and eccrine sweating (sudomotor control). During exercise the only effective avenues of heat loss are through increased blood flow through the cutaneous vasculature and increased sweating.

Water loss from the skin via sweating is an important effector response of the human thermoregulatory system for heat dissipation. The eccrine sweat gland as a thermoregulatory control mechanism is particularly advanced in humans. Lower mammals possess sweat glands but not as developed or numerous. The large surface area of the human skin allows for a large area for evaporation of sweat. The sweat is secreted onto the surface of the skin where it is converted from liquid to water vapour, thereby releasing heat from the body. There are several factors that alter the rate of sweating and the corresponding rate of evaporation such as exercise, environmental conditions, signalling from the nervous system, structure of the sweat gland and skin region. It is well established that the human body surface is non-uniform with regard to the rate of heat transfer. There are many regional differences in skin blood flow, sweating and characteristics of the skin itself (Day, 1967).

Evaporative heat loss plays an essential role in the cooling of the skin and body core during exercise in the heat. When internal body temperature is elevated, sweating occurs at and above a certain core temperature; at what is often termed the "thermoregulatory set-point". The presence of a set-point temperature is evidence for a central sweating control (Boulant, 1981; Sawka and Wenger, 1988). The preoptic area and anterior hypothalamus contain temperature sensitive neurones that respond to alterations in core body temperature and produce effector responses to maintain constant internal temperature

(Adair, 1977). Both the internal (core) temperature and skin temperatures are controlling factors in the sweating response (Nadel *et al.*, 1971; Kondo *et al.*, 1997).

The four million or so sweat glands on the surface of the human body are not uniformly arranged over the entire body surface. Some areas of the body have greater densities of sweat glands than others, with the palms of the hands and soles of the feet having the greatest density at 600-700 glands per square centimetre. In comparison the back only has approximately 64 glands per square centimetre. Taylor (1986) reviewed the recruitment of sweat glands and showed that the consensus of research was for a sweat gland recruitment beginning at the distal areas of the body. A caudal (lower) to rostral (upper) recruitment pattern has been suggested during increasing core temperature and demonstrated in resting subjects (Hertzman *et al.*, 1952; Randall, 1963; Park and Tamura, 1992). The early work of Hertzman and colleagues demonstrated the regional distribution of gland recruitment in the following order:- foot, calf, thigh, abdomen, hand, forearm, arm, chest, and forehead. Cotter and colleagues (1995) investigated the recruitment pattern during exercise and disputed the caudal to rostral pattern, as they found the forehead and scapula had relatively high sweating rates throughout. Ogawa (1984) suggested that posture is a major determinant of regional gland recruitment, by demonstrating that in the standing or seated posture general body sweating appears almost simultaneously, whilst in the supine (lying) posture sweating is usually delayed on the upper half of the body. If a subject was laid on one side, sweating appeared initially on the opposite side.

Hertzman *et al.* (1952) were one of the earliest groups to suggest the mechanisms behind difference in regional evaporation and comparison of evaporation at different environmental temperatures. Their work showed a recruitment pattern, with sweating



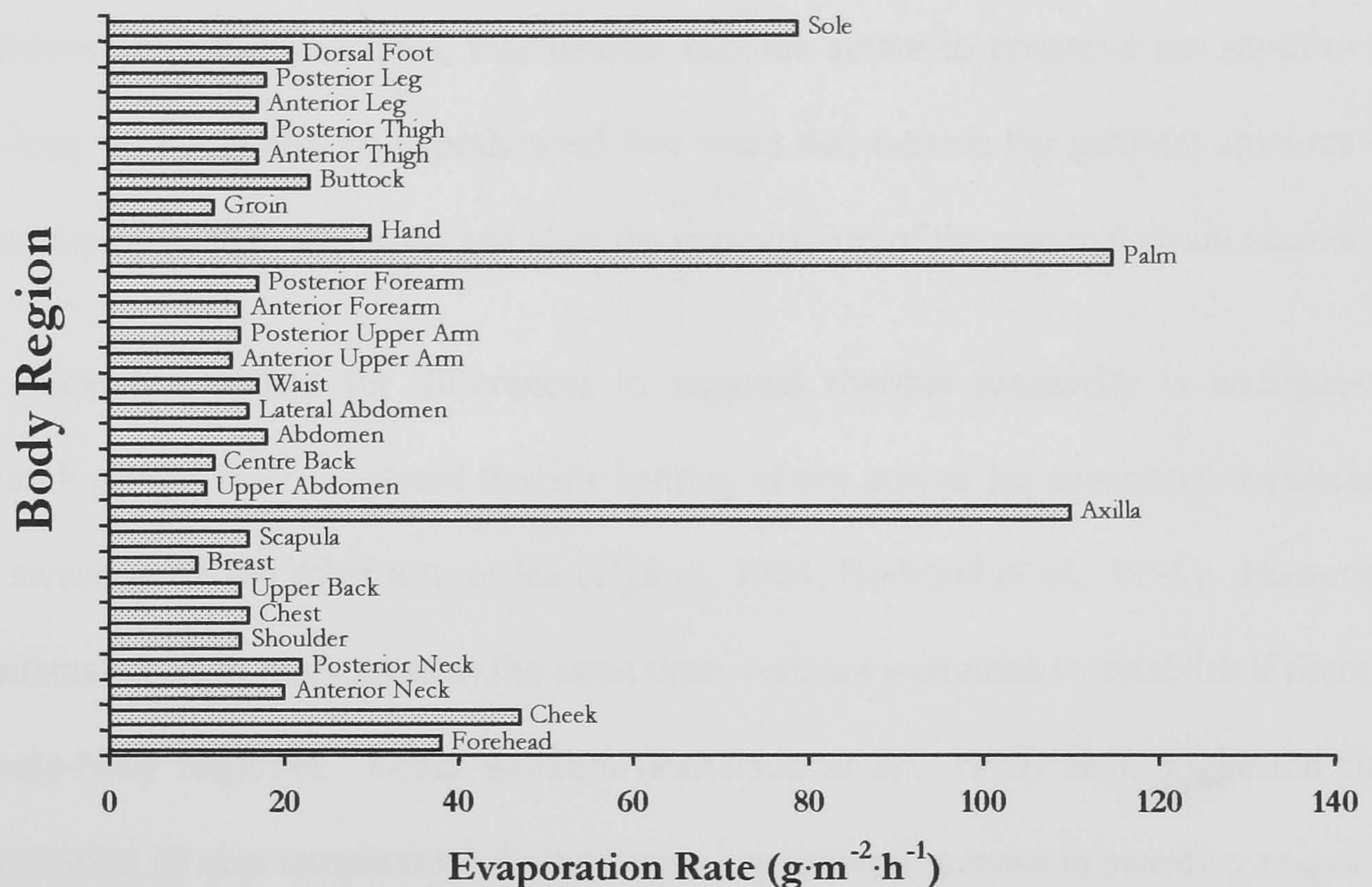
beginning on the dorsal surface of the foot and travelling upwards over the body as evaporative demands increase. This pattern was shown by the sweating onset thresholds for each region and by the sweat-temperature curves for each region. The local skin temperatures were considerably different in each area but Hertzman and colleagues suggested that the mean skin temperature was more of an influence on onset of sweating than local skin temperature. Although mean skin temperature undoubtedly has input into sudomotor control, many authors have since found that an elevated local skin temperature effects a greater sweating rate (Nadel *et al.*, 1971). Once sweating had begun increments in sweating increases were approximately the same for each area. Release of sweat secretion also appears to be symmetrical (Verde *et al.*, 1982).

Individual regions of the human body have different sweating outputs (Hertzman *et al.*, 1952; Nadel *et al.*, 1971; Verde *et al.*, 1982). The chest and back are generally found to have the greatest sweat rates for a given core temperature and sweating thresholds at a lower core temperature. The distal areas of the limbs only sweated profusely at a greatly elevated core temperature but still considerably less than that found on the trunk. Supporting these findings researchers have shown that the threshold for initiation of sweating is lower on the trunk than the limbs (Nadel *et al.*, 1971; Saltin *et al.*, 1972) and Buono (2000) found the recruitment of sweat glands as core temperature increases is greater on the limbs than the trunk. Increases in sweat gland recruitment in all regions were a linear function of core temperature, with some sites increasing at a greater rate than others.

Axilla (armpit), palm and sole have been shown to have significantly higher evaporation rates than any other area of the body (Park and Tamura, 1992) for environmental temperatures ranging from 25°C up to 34°C. At an ambient temperature of 37°C the



evaporation rates for the whole body are greatly elevated and differences between areas are less pronounced. Figure 2.1 shows the differences in evaporation rate at different body regions at a relatively warm ambient temperature of 28°C. The areas of the axilla, sole and palm also show greater relative humidity at the skin surface and greater vapour pressure than other areas. The ambient temperature of 28°C is close to that expected for the 2002 World Cup taking place in Japan and South Korea.



**Figure 2.1.** Localisation of evaporation rate on the skin surface at 28°C ambient temperature. Redrawn from Park and Tamura (1992).

The main ionic constituents of sweat are sodium (Na<sup>2+</sup>), magnesium (Mg<sup>2+</sup>), chloride (Cl<sup>-</sup>), calcium (Ca<sup>2+</sup>) and potassium (K<sup>+</sup>) (Greenleaf *et al.*, 1977; Verde *et al.*, 1982). Sweat glands secrete and reabsorb sweat with individual gland differences resulting in alterations in sweat composition between skin regions (Verde *et al.*, 1982; Shirreffs and Maughan, 1997). Verde and co-workers compared proximal and distal sites on the forearm of both left and right arms. There was no significant difference between arms but



for both arms the proximal sites produced the most sweat. The differences in sweat composition between axilla and forearm were not significant. The authors suggested that the mild experimental conditions may have prevented any possible differences becoming apparent. During intense exercise or under extreme thermal conditions the composition of sweat should be considered. The ions  $Mg^{2+}$  and  $Ca^{2+}$  are important for muscular function. If the sweating rate is high and losses of these two ions are high then muscle fatigue and cardiac disturbance will ensue. It is possible that during exercise with conditions of high sweat rates, mechanisms become active to conserve the supplies of such ions. It could also be hypothesised that areas that excrete the greatest amounts of sweat employ such mechanisms and alter the composition of the regional sweat secretion.

The research evidence for differences in regional thermal sensitivity is ambiguous. Research groups have suggested that the heating of one arm or leg causes a contralateral mild sweating on the other arm or leg (Ogawa, 1984; Bothorel *et al.*, 1991). However, the effects on other body areas at the same time were not examined to establish if there is a whole-body response. Other workers (Patterson *et al.*, 1998) have suggested that manipulation of skin temperature do not cause any greater increase in sweating response at the area stimulated locally compared with areas that are not stimulated. When an area of skin was locally heated there was an increase in sweat rate in all areas of the body. The consensus is that a centrally regulated mechanism for sweating results from integration of thermal afferents, which in turn alters the sweat rate.

During exercise at a constant workload the sweat rate will increase in proportion to the internal body temperature (Nadel *et al.*, 1971; Yamazaki *et al.*, 1993). After exercise the sweating rate is reduced compared to the sweating rate during exercise at the same core temperature. Decreased sudomotor activity is due to post-exercise reductions in

non-thermal factors such as mental excitement and the exposure of descending motor commands to central sudomotor mechanisms, combined with reductions in mean skin temperature (Yamazaki *et al.*, 1993). Core temperature (oesophageal) has been shown to increase for more than 65 minutes following intense activity (Kenny *et al.*, 1997) whilst skin blood flow and mean skin temperature quickly return to pre-exercise levels.

Studies have shown a strong relationship between sweat rate and exercise intensity. Pilardeau *et al.* (1988) found that under neutral environmental conditions there is a linear relationship between relative workload ( $\% \dot{V}O_{2 \max}$ ) and sweat output. Similarly, Kondo *et al.* (1998) showed that mean sweat rate, density of activated sweat glands and sweat gland output all increased with increase in relative workload ( $\% \dot{V}O_{2 \max}$ ). Sweat gland activation and production of sweat may be related to elevated core temperature leading to competition for distribution of cardiac output between skin and active muscle at high intensity exercise. There are conflicting demands between the cooling requirements of the thermoregulatory system in distributing blood to the skin and the requirements of the muscular system in sending blood to the exercising skeletal muscle (Johnson and Park, 1981). At very high exercise intensities there may be a reduction in skin blood flow and consequently a reduced evaporation of sweat resulting in a further elevated core temperature. Sudomotor control then effects an increase in sweating activity in an attempt to attenuate any increases in core temperature.

The metabolic demands of exercise are proportional to the absolute workload. Therefore, the difference in core temperature between individuals is due to their specific ability to dissipate heat. If an athlete has a rapid onset of sweating with sweat glands that produce large quantities of sweat, core temperature will be maintained at a lower temperature than if the onset of sweating was slow and sweat gland responsiveness depressed. In addition



sweat glands may effectively be trained to respond more quickly to thermoregulatory demands (Taylor, 1986; Buono and Sjoholm, 1988; Yamazaki *et al.*, 1994; Armstrong and Maresh, 1998). Although onset of sweating is rapid in trained individuals, the total sweat lost may not be increased due to core temperature being maintained at a lower level, thereby preventing further increases in sweat production.

The regional distribution of the sweating response is also altered after physical training (Taylor, 1986). The response of the limbs to exercise induced thermoregulatory load is improved and sweat distribution was over a larger surface area allowing more effective evaporation and heat dissipation. The large individual differences found by Sato and Dobson (1970) could be explained by differences in the training states of the individual's sweat glands. Whilst there is an increase in sweat rate with increase in workload, this increase does not have a uniform pattern (Takano *et al.*, 1996). Three workloads were tested: 20, 40 and 60% of  $\dot{V}O_{2\max}$  while four separate sites were examined for differences in regional sweating. The research showed a redistribution of sweating towards the head with an increase in exercise intensity. This finding also corroborates the work of Hertzman *et al.* (1952) and Park and Tamura (1992) who showed a similar redistribution with increasing core temperature.

Adequate fluid intake during prolonged exercise is important to prevent thermal injuries and reduced performance (Noakes *et al.*, 1988). As much as 2 l of sweat may be lost per hour during exercise. The amount of sweat lost depends upon factors such as exercise intensity and duration, training status, clothing worn and environmental conditions. The loss of sweat is usually greater than the intake of fluid leading to a state of hypohydration (Sawka, 1992). Replacement of fluids is necessary to prevent further dehydration and reductions in physiological function and performance.

The mechanisms that contribute to dehydration are linked to osmotic and plasma volume regulation (Nose *et al.*, 1988a). Physiological compensation for changes in cellular and extracellular fluid compartments requires modification of kidney function via hormones regulating water and sodium retention and activation of the renal sympathetic nervous system (Mack and Nadel, 1996). The changes in plasma volume are mainly dependent upon the change in total body sodium, which in turn is dependent upon the ability of the kidney to reabsorb water and concentrate urine. Osmoreceptor cells sensitive to the osmolality changes stimulate the release of antidiuretic hormone, more commonly termed as arginine vasopressin (AVP), which acts on the kidney and increases reabsorption of water and hence sodium, conserving body fluids. The renin-angiotensin-aldosterone system is another mechanism for the conservation of body fluid levels and increased levels of aldosterone and plasma renin activity are detected when dehydration occurs (Francesconi *et al.*, 1983; Melin *et al.*, 1997; Montain *et al.*, 1997). These endocrinological mechanisms all serve to prevent or slow dehydration. The nervous system also plays a role in reducing renal blood flow especially during heat stress.

Alterations in the vascular fluid compartment are depicted as changes in plasma volume and give the most accurate indication of hydration status (Jimenez *et al.*, 1999). Urinary indices of hydration level are also commonly used but research is conflicting on the accuracy of these markers for hydration status. Some work suggests that urine colour, osmolality, specific gravity (Armstrong *et al.*, 1998) and urine conductivity (Pollock *et al.*, 1997) are all valid and accurate indices, while other work disputes those findings and suggests urinary markers are not accurate measures during post-exercise rehydration (Kouvacs *et al.*, 1999).



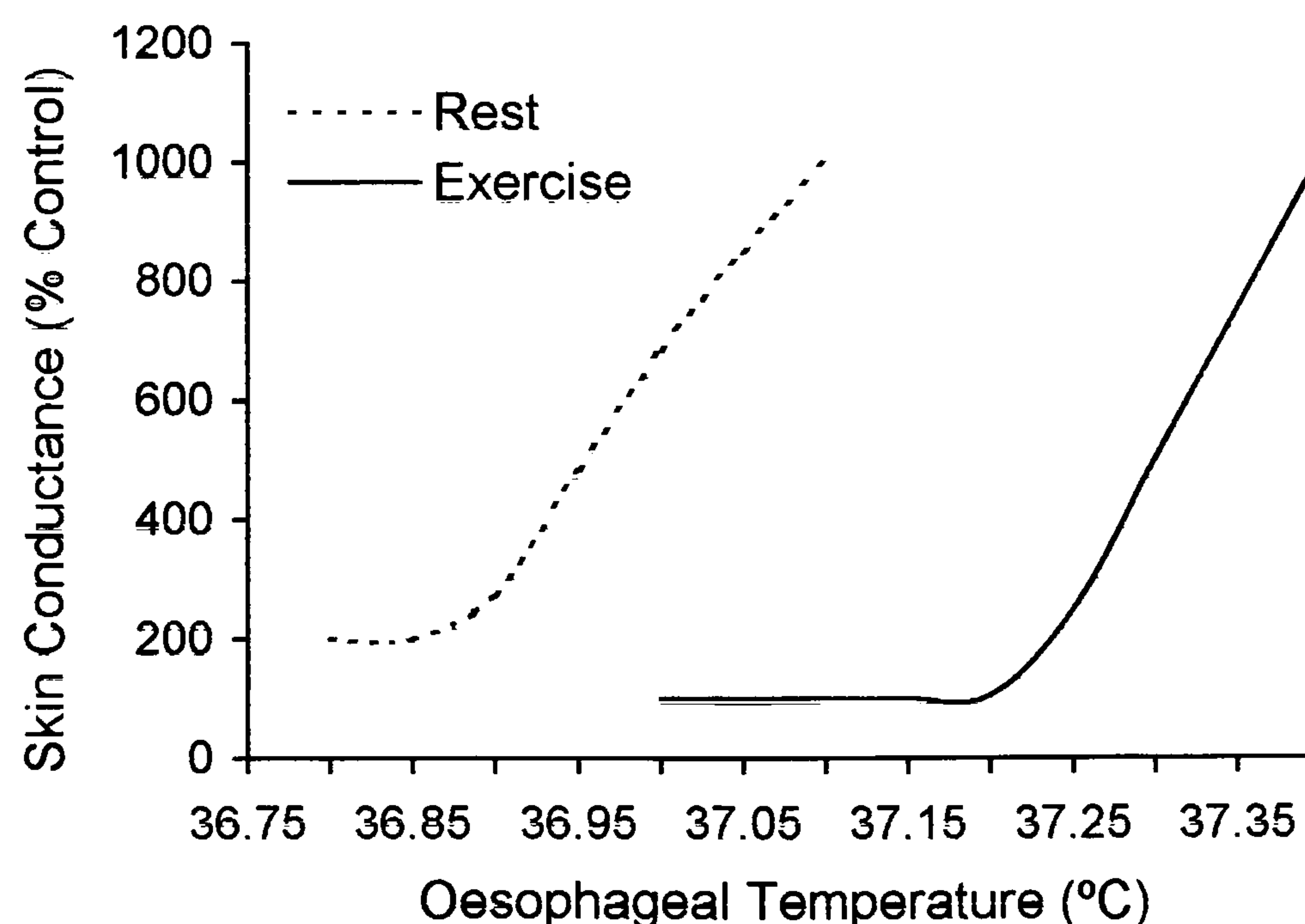
Dehydration during prolonged exercise causes a reduction in total blood volume and stroke volume with a compensatory increase in heart rate. This effect has been termed the “dehydration induced cardiovascular drift” (Coyle, 1998). In fact, dehydration may actually accelerate hyperthermia even in a neutral environment. The cutaneous vasculature constricts when dehydrated (Takamata *et al.*, 1997) even if heat loss is required as the cardiovascular system is responding to a non-thermal drive from baroreceptors in order that the mean arterial pressure is maintained (González-Alonso *et al.*, 1997). Drinking fluids will reverse this response to hyperosmolality (Takamata *et al.*, 1995).

Fluid uptake is largely dependent upon gastric emptying from the stomach into the intestines. Factors that alter the rate of gastric emptying include the volume of fluid, composition of fluid (including the osmolality), temperature of the fluid, psychological stress level, type of exercise and body temperature (Brouns, 1998). Fluid that is retained in the stomach is not available to the body to ease dehydration and it should be noted that drinks with a high carbohydrate (CHO) content are slow to empty from the stomach. Therefore, where fluid replacement is essential CHO concentration should be no greater than 80 g per litre of fluid. The range of current commercially available sports drinks is below this limit (Coombes and Hamilton, 2000). At an exercise intensity commonly found in soccer match-play ( $\sim 70\% \dot{V}O_{2\max}$ ) there is no reported influence on the gastric emptying rate compared to low activity and hence fluid uptake is normal. Significant improvements in intermittent performance have been reported when a carbohydrate and electrolyte drink was consumed (Coggan and Coyle, 1988).

There are two main competitive demands when exercising: the supply of oxygen to the active skeletal muscle to maintain energy metabolism and the transport of heat away from



active tissues to the peripheral cutaneous vasculature for dissipation to the external environment. Circulation of blood in the skin is predominantly thermoregulatory and large alterations in flow are possibly due to the unique construction of the vasculature (Fagrell, 1984). Arteriovenous anastomoses permit the direct shunting of blood from small arteries to a venous network just below the skin surface, negating the need to involve the nutritional blood supply of the skin (Fagrell, 1984). The rise in core temperature associated with exercise affects a thermoregulatory reflex involved in the regulation of skin blood flow (Rowell, 1993). Temperature of the skin also affects thermoregulatory control of skin blood flow, but regulation is primarily dependent upon the level of core temperature (Johnson and Park, 1979). Inhibition of vasoconstriction and activation of vasodilation serve to increase skin blood flow. An interesting response of skin blood flow during exercise is a shift to the right of the threshold for vasodilation. At a given core temperature, skin blood flow is lower during exercise than at rest (Figure 2.2).



**Figure 2.2.** Increase in vasodilatory threshold caused by exercise. (Adapted from Rowell, 1993).

The delay in increased vasodilation may be due to the need to maintain ventricular filling and may also serve to allow an initial increase in core temperature simulating sweat secretion and consequent heat dissipation.

Forearm blood flow can increase 10-fold when an individual has undergone vasodilation and onset of sweating (Wyss *et al.*, 1974). These changes are caused by increases in skin blood flow while blood flow to underlying muscle remains relatively constant (Savage *et al.*, 1993). There is a well-known circadian variation in the internal temperature of humans (Webb, 1995) and a circadian variation in skin blood flow has also been reported (Smolander *et al.*, 1993; Aldemir *et al.*, 2000). The circadian variation of thermoregulatory mechanisms impacts on the interactive relationships between core temperature, skin blood flow and sweat rate during exercise (Aoki *et al.*, 1995) and passive heat stress (Aoki *et al.*, 1998).

Cutaneous blood flow does not increase indefinitely, but at a core temperature of around 38°C a plateau in skin blood flow occurs and there are no further increases even with steady increases in core temperature (Brengelmann *et al.*, 1977; González-Alonso *et al.*, 1999). Inhibition of further increases in skin blood flow are likely to be caused by a baroreflex induced vasoconstriction, which prevents further decreases in central blood pressure (Brengelmann *et al.*, 1977; Roberts and Wenger, 1979; Roberts and Wenger, 1980; Savard *et al.*, 1988; Tripathi *et al.*, 1990; Franklin *et al.*, 1993). Whole-body skin cooling has been observed to enhance the baroreflex control of heart rate (Yamazaki and Sone, 2000), which supports the evidence for interactions between thermoregulation reflexes, in particular skin blood flow, and blood pressure.

Following reductions in central venous pressure induced by passive heating, saline was infused (Crandall *et al.*, 1999). The consequence of saline treatment was a return to



higher pre-heat-stress levels of central venous pressure with a resultant increase in skin blood flow, supporting the suggestion that blood pressure may play an important role in cutaneous vasomotor control (Crandall *et al.*, 1999). However, regional examination of cutaneous blood flow using laser Doppler flowmetry resulted in observations of non-uniform skin blood responses to baroreceptor unloading (localised reduced blood pressure), (Mack, 1998). The shallow depth of measurement of laser Doppler flowmetry may account for non-uniform blood flow measurements, as slightly deeper vasculature, out of range of the laser Doppler, may be also involved in baroreceptor control (Mack, 1998). Nevertheless, regionalism of sweat production has also been reported and the strong relationship between vasomotor and sudomotor responses may be supported by this finding.

Skin blood flow has been observed to be significantly reduced during high intensity (80%  $\dot{V}O_{2\text{ max}}$ ) activity (Smolander *et al.*, 1991), which is likely to be related to elevated core temperature (Bregelmann *et al.*, 1977; González-Alonso *et al.*, 1999) and baroreflex control (Bregelmann *et al.*, 1977; Roberts and Wenger, 1979; Roberts and Wenger, 1980; Tripathi *et al.*, 1990).

When blood is supplied to the cutaneous vasculature, it is warmed from the core. Heat loss may occur through convection of air across the surface of the skin or via evaporation of eccrine sweat secreted on the surface of the skin. Sweat production also places demands upon the body during exercise as fluid loss reduced plasma volume and causes a relative state of dehydration. Reduced central blood volume effects the circulatory system as it attempts to respond to demands for blood supply to both muscle and skin. In conditions of significantly reduced central blood volume, maintenance of blood pressure is met to the cost of other blood flow demands including skin and muscle blood flow. The

consequence of these effects is a reduced time to fatigue (Teller *et al.*, 1998; González-Alonso *et al.*, 1999).

Webb (1995; 1997) has postulated that humans may actually function as regulators of heat rather than the common concept of temperature regulators. A heat loss controller responds to neural signals detecting heat flow. Input from peripheral thermoreceptors may not only detect changes in temperature, but also the changes and direction of heat flow in the skin layers (Ivanov *et al.*, 1982). However, the combined theory of heat control and skin heat flux sensors is very contentious and other researchers entirely disagree with the ability of peripheral sensors to sense heat flow direction (Aizawa and Cabanac, 2000). The input of skin temperature to the hypothalamus has greater influence on behavioural thermoregulation than core temperature does, and serves to prevent the need for more demanding physiological thermoregulatory mechanisms (Bulcao *et al.*, 2000).

Therefore, the overall effect of increased core temperature during exercise is a reduction in performance capacity, this will outlined below in Section 2.2. Effects on performance result from the effector mechanisms in place to protect the human body from overheating.

## **2.2 EXERCISE IN HOT ENVIRONMENTS**

Exercise capacity and exercise performance are reduced when in a hot environment (Galloway and Maughan, 1997; Nielsen *et al.*, 1997). There are major alterations to the cardiovascular system and metabolic functions in an attempt to compensate (Nielsen *et al.*, 1993) for the large sweat losses which lead to hypohydration (Galloway, 1999), in order to maintain core temperature. Marathon runners in hot conditions (35°C) have developed fluid losses of 5% body weight and elevated core temperatures above 40.5°C (Adams *et al.*, 1975).



Reduced time to exhaustion has been observed during activity in a warm environment compared to cooler environments (Galloway and Maughan, 1997). During exercise in a warm environment there is increased metabolic activity, which elevates core temperature and it is this elevation in core temperature that is linked to fatigue (MacDougall *et al.*, 1974; Galloway and Maughan, 1997). Fatigue occurs at the same core temperature independently of core temperature at the start of exercise and is directly related to the rate of heat storage (González-Alonso *et al.*, 1999). Hyperthermia during activity adversely affects muscle metabolism, which will influence time to fatigue. Lactate accumulates within the active muscle and glycogen is more rapidly depleted, limiting power output (Kozlowski *et al.*, 1985). The evidence for a skin blood plateau at a core temperature of 38°C (Brenkelmann *et al.*, 1977) suggests that maximum heat dissipation is reached and further metabolic heat production will result in heat storage or more excessive sweat loss. The plateau is reached in order to maintain muscle blood flow (Savard *et al.*, 1988) and prevent further decreases in peripheral resistance and hence reductions in mean arterial pressure (Franklin *et al.*, 1993). Increased heart rate is directly attributable to reduced stroke volume caused by reduced ventricular filling, dehydration exacerbates these effects and replacement of fluid with a drink containing carbohydrate has been observed to reverse many deleterious effects of hyperthermia, extending the time till exhaustion (Galloway and Maughan, 2000). Fluid replacement with a dilute carbohydrate drink restores blood volume, increasing central blood volume, and replenishes glycogen stores, increasing fuel availability.

### **2.2.1 Cardiorespiratory Responses to Exercise in the Heat**

Cardiovascular demands during exercise in a hot environment are primarily influenced by blood supply demands. Cardiac output is mainly split between supply to the active

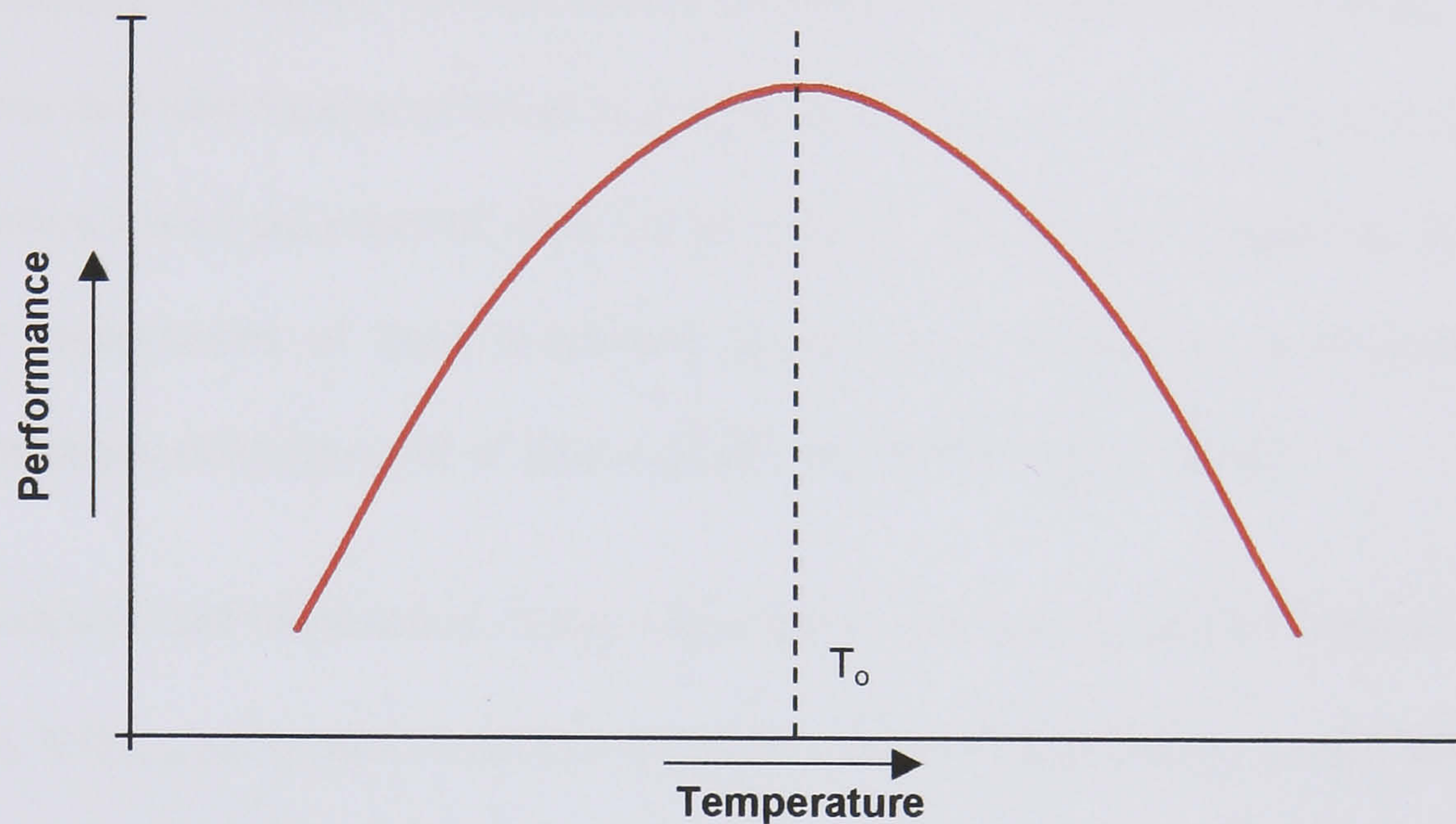


muscles and supply to the cutaneous circulation for peripheral dissipation of heat. Insufficient blood supply to the active muscle during exercise in the heat may cause changes in muscle metabolism resulting in earlier time to fatigue (González-Alonso *et al.*, 1998). Conversely, reduced blood flow to the skin results in further increases in body temperature, also limiting endurance capability. During exercise, the function of active muscle is dependent upon blood flow to the muscle while at the same time the cutaneous vascular beds require sufficient blood to allow for cooling. This conflict of demand is exacerbated in hot environments with a 20% reduction in stroke volume observed in a hot environment compared to a neutral environment (Rowell, 1983a). Inadequate perfusion of the working muscle will result in a decrease in exercise capacity and inadequate perfusion of cutaneous vasculature will result in hyperthermia. Both outcomes will cause the early termination of exercise. However, it has also been postulated that muscle blood flow is not reduced in humans during moderate exercise and heat stress (Savard *et al.*, 1988). Measurements of oxygen utilisation within working muscles have shown no differences between three different temperature conditions where mean skin temperature was maintained using a water-perfused suit ( $\bar{T}_{sk}$  at 31°C, 35°C and 38°C). This finding indicates the aerobic capacity of the active muscle has not been compromised and circulation is meeting blood supply requirements. Uncompensable heat stress is the condition when the human body is unable to maintain thermal steady state due to excessive heat load from metabolic and/or environmental origins (Cheung *et al.*, 2000).

The changes that occur during acute exercise in the heat represent an attempt to maintain performance capability. Nevertheless, time to fatigue is still reduced in exercise in the heat. Febbraio and co-workers (1996) showed time to fatigue during exercise at 70% of  $\dot{V}O_{2\text{ peak}}$  was  $67 \pm 1$  min at 20°C and  $30 \pm 3$  min at 40°C. Performance of difficult tasks, such as soccer skills, are affected by environmental temperature resulting in an inverted U



relationship where maximum performance occurs at an optimal temperature ( $T_o$ ) and level of arousal (McIntyre, 1980):



**Figure 2.3.** Theoretical prediction of performance effected by temperature for a difficult task. Redrawn from McIntyre (1980).

### 2.2.2 Metabolic Responses to Exercise in the Heat

The capacity for exercise is reduced in a warm environment due to increased heat storage and greater thermoregulatory demand for heat dissipation. Blood flow to the active muscle may be compromised evidence for this has been shown by a reduction in time to exhaustion (González-Alonso *et al.*, 1998). A restriction to prolonged exercise in warm, in dogs, was reported to be due to the effects of temperature on muscle metabolism (Kozlowski *et al.*, 1985). The active muscle may be affected by alterations in substrate concentrations, oxygen availability and circulating hormones (Febbraio *et al.*, 1994) impacting upon energy metabolism. Increased utilisation of ATP (adenosine tri-phosphate), the basic molecule that provides energy, reported during heat stress is met



by increases in anaerobic glycolysis (Febbraio *et al.*, 1994). Elevated muscle glycogen utilisation (anaerobic contribution), and hence glycogen depletion, results in acceleration in time to fatigue (Galloway and Maughan, 2000). The increase in glycogen utilisation is exemplified by accumulation of lactate in the active muscle and increase in blood lactate concentration. However, reduced lactate elimination may explain the increases in blood lactate as the redistribution of blood from splanchnic areas to active muscle and cutaneous vasculature lowers the removal of lactate at the liver. The onset of fatigue can be delayed by the replacement of fluid containing glucose and electrolytes, with more dilute concentrations delaying onset of fatigue (Galloway and Maughan, 2000).

The metabolic and biochemical changes associated with prolonged, high intensity activity ( $> 60\% \dot{V}O_{2\max}$ ) may also contribute to cardiovascular drift (Cheatham *et al.*, 2000) via a greater demand for blood supply to active muscle. Increases in catecholamines have been reported during prolonged activity and are well understood to elevate heart rate, blood pressure and cardiac output (Halter *et al.*, 1984).

Free fatty acids (FFA) are a major fuel source for muscle metabolism at rest and during low to moderate levels of exercise. At the same exercise intensity, trained individuals show an increased utilisation of FFA than untrained individuals (Turcotte *et al.*, 1992).

The fuel provision for the first 2 h of activity ( $60\% \dot{V}O_{2\max}$ ) was similar between both trained and untrained persons. The last 60 min (also  $60\% \dot{V}O_{2\max}$ ), was different with trained individuals showing no differences between the first 2 h and the last 60 min of exercise, while untrained individuals displayed a greater reliance on carbohydrate energy provision in the last 60 min. The resulting sparing of carbohydrate fuel sources in trained individuals allows a greater time till onset of fatigue. Increased utilisation of FFA by trained individuals may help explain their increased tolerance to heat



Oxygen consumption during exercise in warm environments was reported to be reduced by Galloway and Maughan (1997). During the same conditions of exercise at different environmental temperatures, Galloway and Maughan (1997) observed a mean end of exercise  $\dot{V}O_2$  of 2.6 l min<sup>-1</sup> during exercise at 31°C, 2.7 l min<sup>-1</sup> at 21°C, 2.9 l min<sup>-1</sup> at 21°C and 3.6 l min<sup>-1</sup> at 21°C. The reduction in  $\dot{V}O_2$  at increased environmental temperature may be due to increased demands on cutaneous heat dissipation. As blood volume in the peripheral vasculature increases, central blood volume falls, which may impact upon the volume of blood, supplied to the pulmonary circulation, affecting oxygen uptake and subsequent delivery to active tissue.

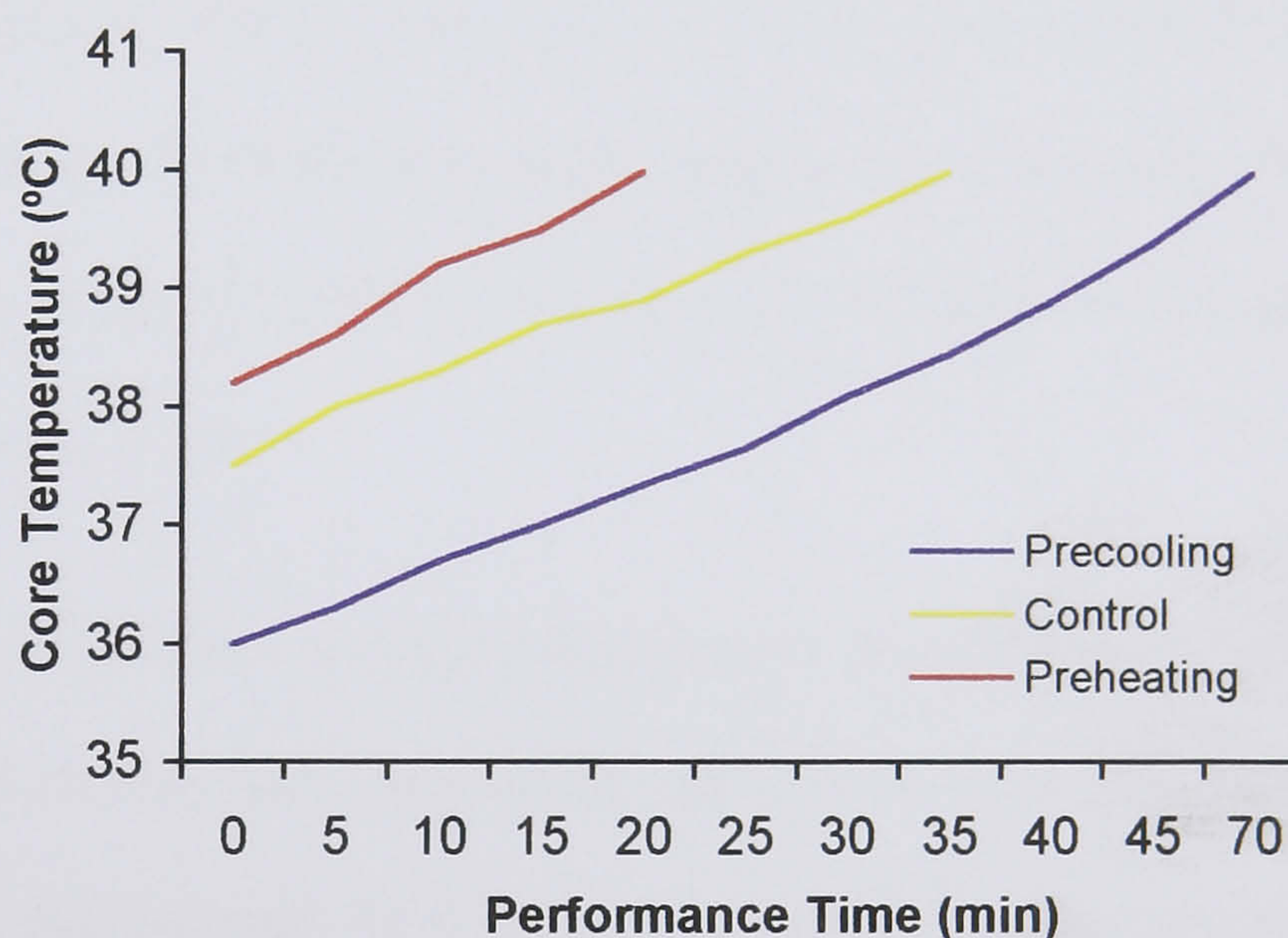
### **2.2.3 Thermoregulatory Responses to Exercise in the Heat**

In a hot and humid environment there are demands from both the active muscle and the skin to provide peripheral cooling. The ability to dissipate heat may be reduced and further worsened by dehydration leading to a reduction in endurance performance (MacDougall *et al.*, 1974; Galloway and Maughan, 1997). Core temperature has been identified as a critical factor in the development of fatigue in conditions of steady-state activity (Nielsen *et al.*, 1993; Galloway and Maughan, 1997; Teller *et al.*, 1998; González-Alonso *et al.*, 1999).

During prolonged exercise to volitional exhaustion in environmental conditions of 40°C, it has been suggested that core temperature is the causative factor in the development of fatigue (Teller *et al.*, 1998; González-Alonso *et al.*, 1999). When subjects were pre-cooled prior to exercise, time to exhaustion was increased compared to control and pre-heating trials. An inverse relationship between initial core temperature and time to volitional exhaustion has been described (González-Alonso *et al.*, 1999). Regardless of starting core temperature, state of training or state of acclimation, fatigue occurred at the



same final core temperature (Nielsen *et al.*, 1993; Aoyagi *et al.*, 1994; González-Alonso *et al.*, 1999) illustrated in Figure 2.4. Therefore, when individuals are pre-cooled, the starting core temperature is reduced and time to exhaustion is consequently increased (Booth *et al.*, 1997), although benefits of pre-cooling are greatly reduced with increasing duration of exercise (Drust *et al.*, 2000). Heart rate and mean skin temperature responses also mimic core temperature, with higher heart rates and skin temperatures occurring with higher core temperature and volitional exhaustion occurring at the same maximum responses.



**Figure 2.4.** Core temperature response during exercise in the heat (40°C, 17% RH) during precooling, control and preheating trials. Redrawn from González-Alonso *et al.* (1999).

The increase in core temperature during exercise is dependent upon relative workload and independent of environmental conditions and exercise duration (Smolander *et al.*, 1991; Moran *et al.*, 1996). Nielsen's original work (as quoted by Sawka *et al.* 1996) showed that total heat loss, heat storage and core temperature were the same in environmental conditions between 5°C and 36°C. Later research showed that core temperature was independent of the environment only within a "prescriptive zone" (Sawka *et al.*, 1996), a

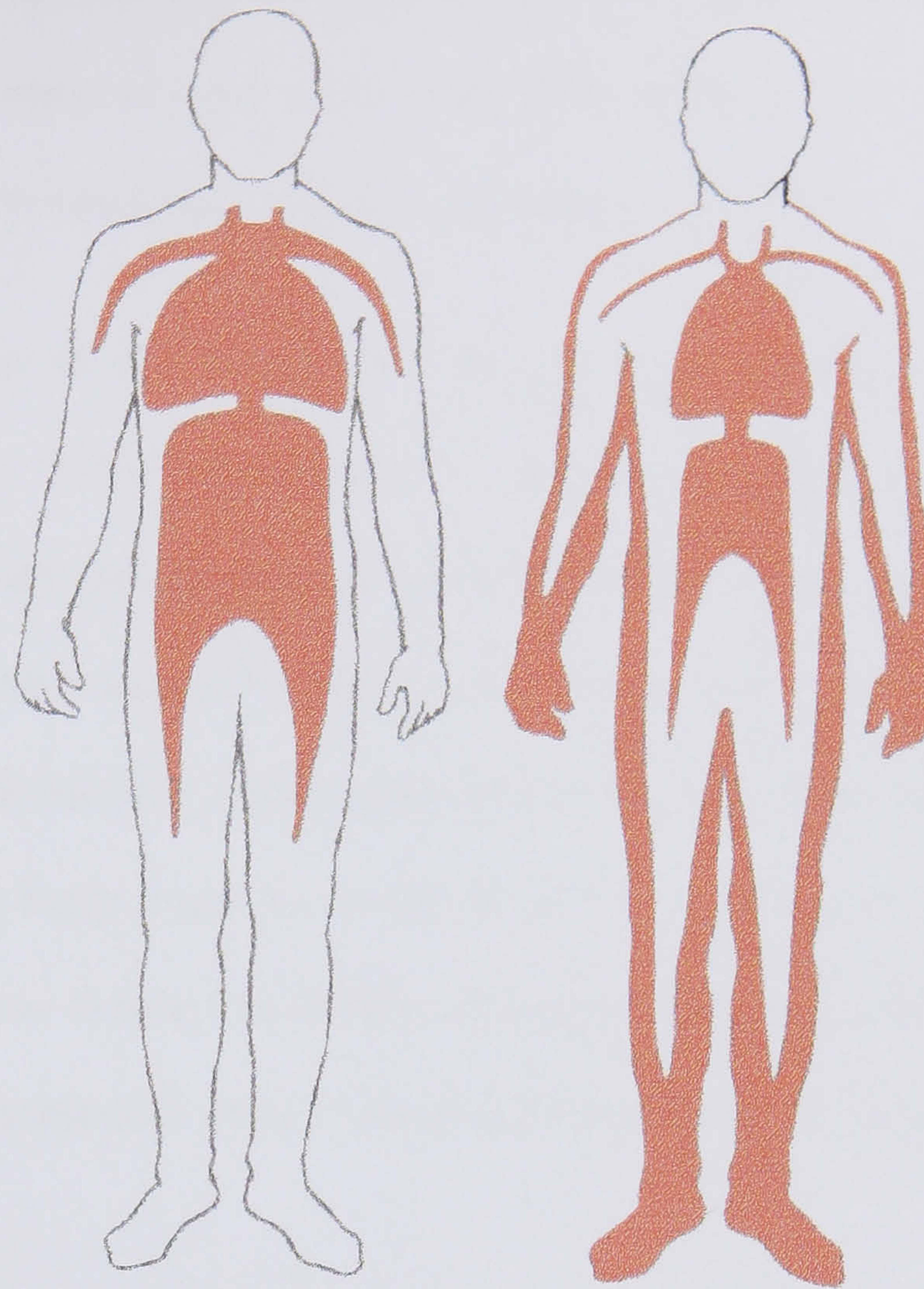


range of particular conditions. The greater the metabolic rate the lower the upper environmental temperature limit for the prescriptive zone.

Environment characteristics significantly alter the physiological responses of the body in order to disperse the extra heat load created during exercise. Afferent signals from thermosensors in the core and skin alter efferent responses from the thermoregulatory centre with the rate of change in ambient temperature being important in modifying the effector responses (Werner, 1983). A rapid increase in ambient temperature produced an immediate reduction in metabolic heat production and delayed onset of sweating on the chest, forehead and arm. Sweat production of the hand also increased with rapid onset but the overall magnitude of increase was not as great as the other areas. The hands and feet have been shown to display different evaporative rates and thermoregulatory properties (Werner and Reents, 1980).

Changes in skin temperature and core temperature caused by exercise or environmental stimuli serve to stimulate thermoregulatory adjustments in skin blood flow (Wyss *et al.*, 1974). Blood is redistributed from the central tissues to more peripheral tissues during heating (Cai *et al.*, 2000). During conditions of heat stress intracellular fluids are increased as an attempt to maintain plasma volume occurs at the detriment of extracellular fluid (Maw *et al.*, 1998; Cai *et al.*, 2000). A representation of the altered distribution of the majority of blood volume in a heat stressed individual at rest was illustrated by Rowell (1983a) and is shown below in Figure 2.5.





**Figure 2.5.** Altered distribution of blood volume from a cool state (left) to a heat-stressed state (right). Adapted from Rowell (1983a).

Heat loss during thermal stress is facilitated by rapid processing of blood through the cutaneous circulation (Abraham *et al.*, 1994). Cardiac output increases with increasing mean skin temperature, the majority of the extra volume of blood being directed to the skin with additional blood redirected from the splanchnic and renal vascular beds in order to meet thermoregulatory demands (González-Alonso *et al.*, 1998). When thermoregulatory demands are great, a threshold for skin blood flow will be met at the expense of heat loss. This mechanism occurs to maintain mean arterial pressure and blood supply to the working skeletal muscle (González-Alonso *et al.*, 1998).



Skin blood flow responds to a circadian rhythm in the same way that core temperature changes over the course of a day (Aoki *et al.*, 1998; Aldemir *et al.*, 2000). The response is due to a rhythm in vasoconstrictor activity (Aoki *et al.*, 1998).

Regional responses of skin blood flow are related to the regional responses of the sweating responses. When skin blood flow was plotted as a function of mean sweat rate there are three clearly defined phases (Aoki *et al.*, 1998). Phase A is an initial increase in skin blood flow without onset of sweating (reduced vasomotor tone), followed by phase B during which skin blood flow remains constant and sweat production increases (due to the sweating threshold being reached), finally phase C is a linear increase in both sweating and skin blood flow (active vasodilation associated with sweating activity). Phase A displays a circadian response while Phase B and Phase C do not show any variation (Aoki *et al.*, 1998).

Supplementary to central inputs to thermoregulatory control of skin blood flow (Wyss *et al.*, 1974), localised temperature of the blood vessels is also thought to contribute to the volume of local skin blood flow (Charkoudian *et al.*, 1999). Independent warming of skin blood vessels has demonstrated a marked vasodilation which is not controlled by central vasomotor activity (Charkoudian *et al.*, 1999).

The velocity of air surrounding an individual is an important consideration for heat dissipation. Faster air increases evaporative and convective heat transfer coefficients allowing for more effective heat liberation. Comparison between still air and moving air has shown a decreased skin temperature, sweat loss and core temperature in conditions of high air velocity (Adams *et al.*, 1992; Kwon *et al.*, 1998). The greater movement of air allowing for increased evaporation of sweat from the skin, reducing overall sweat production.

Davies et al. (1971) observed the effects of intense exercise on temperature regulation and skin wettedness. They reported that skin wettedness causes a decrease in evaporative sweat loss of approximately 10%. The mechanisms underlying hidromeiosis are unknown. One postulated mechanism is the possibility of the layer of skin known as the stratum corneum swelling and mechanically obstructing the duct. Another hypothesis relates to the reduction, due to dilution, of an osmotic gradient from the proximal duct of the sweat gland to the skin surface. It has also been suggested that by negative feedback, wet skin reduces sweat gland output locally (Sawka and Wenger, 1988). Whatever the causes behind hidromeiosis, its effect is likely to be a mechanism for the conservation of body water to prevent dehydration.

Core temperature and dehydration are thought to be primary factors in causation of central fatigue; as plasma concentrations of tryptophan increase mediated by dehydration, transport across the blood-brain barrier is elevated resulting in increased rate of serotonin synthesis. Branched-chain amino acids balance tryptophan and it is the free plasma tryptophan that stimulates serotonin synthesis (Blomstrand *et al.*, 1988). Administration of branched-chain amino acids during exercise in the heat by Mittleman *et al.* (1998) resulted in a significant enhancement of performance by prolonging time to fatigue. The actions of serotonin in the brain are thought to be related to mood and sleep, and these actions may explain central fatigue during heat stress (Davis and Bailey, 1997). Prolactin has been reported to be a marker of brain serotonergic activity and high levels following exposure to a warm environment (Kukkonen-Harjula *et al.*, 1989) give evidence to the impact of core temperature on central fatigue. (Prolactin is investigated in further detail in the subsequent section starting on page 36). Fluid losses during exercise occur due to the increase in core temperature that subsequently initiates sweating, although as dehydration progresses there is a decrease in sweating and core temperature increases



(Davis and Yousef, 1987). Increased core temperature has successfully been linked to cessation of exercise independently of cardiovascular stress (Hoffman *et al.*, 1994; Galloway and Maughan, 1997), tying together the concepts of core temperature, dehydration and central factors to the development of fatigue. Hypohydration has been shown to increase the sweating onset threshold significantly. Montain *et al.* (1995) showed that for a 5% body weight loss (BWL) there is a gain of  $0.09^{\circ}\text{C}/\%\text{BWL}$  on the sweating threshold. Sawka *et al.* (1985) found a higher increase stating that for the 5% loss of body weight tested there was a gain of  $0.11^{\circ}\text{C}/\%\text{BWL}$ .

Time to fatigue following prolonged exercise at 60% of  $\dot{V}\text{O}_{2\text{max}}$  in warm environmental conditions of  $30^{\circ}\text{C}$  and 70% RH was shown to be almost doubled when a diluted carbohydrate (2%) drink was administered to counteract dehydration compared to a no-drink treatment (Galloway and Maughan, 2000). The concentration of blood lactate was also found to be reduced following exercise, serum osmolality was lower (more hydrated) and the change in plasma volume was significantly less at all times with plasma volume being restored to pre-exercise volume on completion of the exercise. Consumption of a smaller volume of fluid with a greater concentration of carbohydrate (15%) showed beneficial effects compared to a no-drink trial, but was less beneficial than the administration of a fluid of greater volume but lower carbohydrate concentration.

#### **2.2.4 Endocrinological Responses to Exercise in the Heat**

Prolactin is secreted from the anterior pituitary and its most prominent function is the stimulation of lactations during pregnancy although blood prolactin responses have also been associated with exercise stress (Tyrrell *et al.*, 1994). The release of prolactin is controlled by the hypothalamus with dopamine controlling release as an inhibitory factor and thyrotropin-releasing-hormone contributing to lesser degree as a stimulating factor



(Mills and Robertshaw, 1981; Tyrrell *et al.*, 1994; Colthorpe *et al.*, 1998). Serotonin has also been linked to the release of prolactin (Strachan and Maughan, 1999) and increases in blood prolactin concentration have been linked to thermal stress (Brisson *et al.*, 1986; Laatikainen *et al.*, 1988; Melin *et al.*, 1988; Falk *et al.*, 1991). Exercise at core temperature greater than 38°C has been reported to reduce central drive for motor performance contributing to onset of fatigue. The resulting adverse effect on the central nervous system (Nielsen *et al.*, 1990) has been related to central serotonergic (5-hydroxytryptamine) activity with increased prolactin concentration as a marker of that central fatigue (Blomstrand *et al.*, 1988; Davis and Bailey, 1997).

Parameters associated with thermal stress have also been associated with increases in prolactin concentration: blood osmolality (Horrobin, 1980), sweat composition (Robertson *et al.*, 1986) and sweat gland function (Walker *et al.*, 1989). Consequently a rise in blood prolactin may alter the electrolyte composition and volume of body fluids in response to a thermal load. Mills *et al.* (1981) performed an analysis of the response of plasma prolactin to changes in mean body temperature in resting subjects and found a strong correlation ( $r = 0.96$ ). The response of prolactin to thermal stress is also suggested by the observations of prolactin inhibition under cool conditions (Mills and Robertshaw, 1981; Brisson *et al.*, 1989).

Prolonged exercise in warm conditions leads to increasing dehydration due to sweat production and changes in cutaneous perfusion causing fluid to move from the blood into the interstitial fluid (Fortney *et al.*, 1981; Nose *et al.*, 1988b). A decrease in plasma volume and an increase in osmolality are evidence of this (Brandenberger *et al.*, 1986) with heart rate progressively increasing to compensate for reduced filling and a concurrently reduced stroke volume (Fortney *et al.*, 1981). Fluid regulation and



electrolyte excretion are maintained by two prominent hormonal systems; these are the renin-angiotensin-aldosterone system and the antidiuretic hormone (or arginine vasopressin, AVP) system.

Renal blood flow and filtration rate are known to decrease during exercise (Wesson, 1969) with the proportion of reduction dependent on the intensity of exercise. During exercise, efferent impulses from the sympathetic nervous system constrict the blood vessels in the kidney in order to divert the blood supply to the muscles. This reduction in renal blood flow stimulates the release of renin from the kidney, in turn stimulating angiotensin secretion, which then stimulates the release of aldosterone from the adrenal cortex (Davis and Knox, 1970). The release of antidiuretic hormone (ADH) is also stimulated (Valtin and Schafer, 1995). Both aldosterone and ADH increase the reabsorption of sodium and water with a concomitant increase in potassium excretion, increasing blood volume and hence blood pressure (Davis and Knox, 1970; Hamby, 1971; Valtin and Schafer, 1995).

When exercising in a hot environment of 34°C, subjects showed increases in aldosterone, renin activity and ADH (Brandenberger *et al.*, 1986). All changes were attenuated by intake of isotonic fluid while water also attenuated plasma renin activity, increases in AVP, but not aldosterone. The hormone cortisol is also released in response to stressful conditions and concentrations do not change when either water or isotonic fluid is consumed compared to a significant increase without fluid increase. Expansion of plasma volume by increasing fluid intake has been shown to be beneficial prior to exercise in hot conditions, with thermoregulatory and cardiovascular demands being reduced (Nose *et al.*, 1990). The adjustments during repeated exposure to heat during acclimatisation have



been shown to include plasma volume expansion as a significant factor in improved heat tolerance (Senay and Kok, 1976; Senay *et al.*, 1976).

### **2.3 EXERCISE IN COLD ENVIRONMENTS**

Typically, cold stress presents less of a danger than heat stress due to the greater availability of measures to protect an individual. These measures can include shelter and clothing to prevent heat loss, and increasing physical activity to elevate internal heat production. If the microclimate of the skin is maintained at a comfortable temperature through wearing suitable clothing, an individual can maintain body temperature and tolerate very low ambient temperatures. These behavioural and activity mechanisms to offset hypothermia may not always be possible if shelter or adequate clothing is not available or fatigue prevents further increases in activity level. An early investigation into cold exposure showed that 1 h of activity at 0 °C induced exhaustion and confusion in individuals who have previously carried out the same exercise intensity for 4 h (Adolf and Molnar, 1946). Pugh (1967) found similar effects at 5 °C while exercise carried out at -20°C reduced time to exhaustion by 38% compared to the same exercise at +20°C (Patton and Vogel, 1984). Mild cooling at 10 °C has also been found to increase energy expenditure during endurance exercise lasting 90 minutes compared to the same exercise at 15 °C (Sjödín *et al.*, 1996).

Physiological heat retention mechanisms are brought into play when thermoreceptors in the core and skin are stimulated by the cold. These mechanisms include vasoconstriction of cutaneous vasculature, elevation of basal metabolism and piloerection of hairs on the surface of the skin, and reduce the risk of hypothermia. Vasoconstriction of the skin blood vessels is initiated by sympathetic nervous activity, which results in contraction of the walls of the vessels. Blood volume in the periphery is decreased so heat is not



dissipated to the environment, hence maintaining core temperature. Elevation of basal heat production is stimulated by neuroendocrine mechanisms activated by the hypothalamus. The thyroid and adrenal glands are affected with the release of thyroxine causing an increase in metabolic rate within 5-6 hours of cold exposure. Adrenaline and adrencortical hormones also cause a slight increase in metabolism.

Wind velocity is an important factor in body cooling in that the ambient temperature alone may under-estimate actual environmental risk. The wind-chill index derived by Siple and Passel (1945) is a method of comparing different combinations of temperature and wind speed, presented as a scale ranging from hot, through bitterly cold, down to a condition where exposed flesh freezes within 30 s. The Wind Chill Index presents "temperature equivalents" and can be estimated with a nomogram. The index enables estimation of effective cold stress and allows participants in outdoor activities to take appropriate precautions.

Physical training usually involves loss of fat deposits and the consequent loss of insulation against cold. Trained subjects have been reported to maintain increased oxygen consumption and shivering while asleep better than untrained subjects (Anderson *et al.*, 1966). However, trained individuals are able to sustain a greater activity level voluntarily and are more likely to avoid hypothermia when active outdoors.

### **2.3.1 Cardiorespiratory Responses to Exercise in the Cold**

Elevated oxygen consumption has been observed (Galloway and Maughan, 1997) during continuous activity of approximately 70%  $\dot{V}O_{2 \text{ max}}$  at temperatures of 4°C and 11°C compared to 21°C and 31°C. Similar findings of elevated oxygen consumption resulted from exercise in environmental conditions of -10°C compared to 22°C (Timmons *et al.*,



1985). Factors responsible for increased oxygen demands may be the effects of cold upon the respiratory system. There are conflicting findings in the literature concerning the effects of cold stress on the respiratory system. Shivering thermogenesis occurs when the core has cooled and both  $\dot{V}O_2$  and  $V_E$  increase. Thermogenesis increases metabolism and increases oxygen consumption and ventilation as a mechanism to maintain core temperature (Weller *et al.*, 1997). During exercise in cold conditions core temperature may be maintained while the periphery is still cooled. During these circumstances ventilation and oxygen consumption are thought to increase as a result of thermal receptors in the skin, increases in muscle metabolism and increased muscle tension (Giesbrecht, 1995). However, other research has failed to find a difference in ventilation or oxygen consumption during cold exposure (Pendergast, 1988).

Breathing cold air during exercise has been observed to invoke a slight physiological demand including increased diastolic blood pressure, rectal temperature and heart rate (Hartung *et al.*, 1980). However, oxygen consumption, ventilation, RER and forced expiratory volume were not significantly affected (Hartung *et al.*, 1980; Pekkarinen *et al.*, 1989). It may be that the exercise intensity and duration are determining factors in pulmonary function independently of the temperature of the inspired air (Chapman *et al.*, 1990).

Regular exercise has been shown to improve the cardiorespiratory response to an exercise bout. The vascular bed, muscle and heart increase in size, thereby improving work capacity and also heat production. High levels of oxygen consumption in a fit and trained individual allow for more intense and more prolonged exercise. Therefore high maximal oxygen consumption may also allow for improved cold tolerance when exercise is necessary for the maintenance of core temperature (Bittel *et al.*, 1988).



### 2.3.2 Metabolic Responses to Exercise in the Cold

During exercise in the cold, enhanced fat utilisation has been suggested as the major contribution to energy provision (Hurley and Haymes, 1982; Timmons *et al.*, 1985) although other work disputes this finding, suggesting no difference in fat energy expenditure during the cold (Sink *et al.*, 1989) or increased use of carbohydrate (Vallerand and Jacobs, 1990). As tissue temperature decreases all metabolic reactions are slowed (Pendergast, 1988) as the blood supply, and hence oxygen supply, to the tissue is reduced. Lowered muscle temperature due to prior immersion in water at 12°C has been reported to cause higher blood lactate concentration during exercise compared to the same activity following rest at room temperature (Beelen and Sargeant, 1991). The increase in blood lactate concentration is likely to be a product of greater reliance on anaerobic energy production at the onset of exercise when muscle temperature is lowest following immersion cooling.

Cold promotes free fatty acid mobilisation and utilisation during rest and increased mobilisation during exercise (Foster *et al.*, 1979). The metabolism of fat at rest during cold exposure occurs in order for thermogenesis to produce the necessary heat to maintain core temperature (Leblanc, 1988). Timmons *et al.* (1985) reported elevated fat utilisation and little contribution by carbohydrate during exercise in very cold conditions of -10°C. The increased fat utilisation and oxygen consumption was purported to be an additive effect of moderate exercise and thermogenic metabolism. The findings that carbohydrate did not contribute to the increased metabolism is contrary to other findings where elevated blood lactate suggests increased glycolytic energy production (Beelen and Sargeant, 1991).



The causes of fatigue during prolonged exercise, at the intensity found in soccer match-play ( $\sim 70\% \dot{V}O_{2 \max}$ ), in a cold environment are different from the causes of fatigue in a warm environment (Pitsiladis and Maughan, 1999). Whereas fatigue in warm environments is likely to be due to elevated core temperature (Teller *et al.*, 1998), fatigue in the cold is caused by muscle glycogen depletion (Vallerand and Jacobs, 1989; Galloway and Maughan, 1998; Pitsiladis and Maughan, 1999). Galloway and Maughan (1998) tested the hypothesis that during prolonged exercise in a cold environment, fatigue is dependent upon the available glycogen stores. They performed three tests at  $10^{\circ}\text{C}$ ,  $80\% \dot{V}O_{2 \max}$ : no drink, a 15% carbohydrate (CHO) drink and a 2% CHO drink. No significant differences were found between trials, suggesting that glycogen stores may not be the limiting factor during exercise in conditions of mild cold. The contrasting results of current research are probably due to methodological and environmental differences.

Differences in cold tolerance have been attributed to subcutaneous fat thickness (Bittel *et al.*, 1988) where the fat acts as an insulator. Mean skin temperature is directly dependent upon the peripheral insulation caused by vasomotor tone although mean skin temperature has been shown primarily to be dependent ambient temperature with percentage body fat also playing a significant role in cold tolerance.

Oxygen consumption during exercise in the cold is variable and conflicting results have been reported, differences in methodology are the probable causes of contrasting results (Galloway and Maughan, 1997). Nevertheless, the general consensus is a higher oxygen consumption in a cold environment. Hurley and Haymes (1982) and Galloway and Maughan (1997) and Sjödín *et al.* (1996) all reported increases in  $\dot{V}O_2$  during exercise in the cold despite a similar time to exhaustion to that at neutral conditions (Hurley and Haymes, 1982; Galloway and Maughan, 1997). Preferential utilization of fat may



account for higher aerobic contribution and hence higher oxygen consumption (Fink *et al.*, 1975; Hurley and Haymes, 1982).

### 2.3.3 Thermoregulatory Responses to Exercise in the Cold

A three phase response pattern of the skin to extreme prolonged cold exposure has been reported in sedentary individuals (Shitzer *et al.*, 1998). On exposure skin temperature falls relatively slowly, due to delayed vasoconstriction, and this response can last for several minutes. The second phase results in a rapid decrease in skin temperature concomitantly with a vasoconstriction of the cutaneous vasculature (Sendowski *et al.*, 2000). Approximately 10 min following this response, skin temperature begins to rise due to a cold induced vasodilation. The cutaneous vasculature shortly constricts again and throughout the exposure to the cold there are periodic increases in peripheral blood flow. These short increases in skin blood flow serve as a protective mechanism to prevent cold injury to the extremities i.e. frostbite (O'Brien *et al.*, 1998). Skin temperature ( $\bar{T}_{sk}$ ) is a determining factor in the time of onset of cold induced vasodilation, while core temperature determines the magnitude of the dilatory response (Sendowski *et al.*, 2000). During prolonged and more severe cold exposure the intermittent vasodilation disappears and cutaneous blood flow is entirely restricted (Fox, 1967). In some individuals, all three phases are not evident, however the second phase of vasoconstriction is always apparent (Shitzer *et al.*, 1998).

The problems of dehydration associated with exercise in warm environments does not occur in cold environments. The necessity for sweat production and evaporation in the cold for heat dissipation is not present. Conflicting demands for skin blood flow and muscle blood flow do not occur and even when hypohydration is forced in laboratory



settings, there is no appreciable effect on thermoregulation (O'Brien *et al.*, 1995; O'Brien *et al.*, 1998).

## **2.4 SOCCER SPECIFIC INTERMITTENT EXERCISE**

The physiological demands of soccer are characterised by the variable intensities of low to moderate activities such as walking, jogging and running superimposed with high intensity activity such as cruising and maximal sprinting (Bangsbo, 1994b). The intensity of the exercise can alter at any time and up to 1000 changes in activity have been reported (Reilly and Thomas, 1976) with mean duration of 5 - 6 s for each activity bout. Intermittent exercise has been shown to induce higher physiological demands compared with continuous exercise of the same overall work-rate (Palmer *et al.*, 1999) and these differences are also found specifically in soccer activity (Bangsbo, 1994c; Drust, 1997). When the duration of an exercise bout is less than 2 min, the responses of the cardiovascular system lag behind any changes in muscle activity (Palmer *et al.*, 1999). This delay may be one of the factors, which account for the higher demands of soccer type activity compared to steady state activity at the same overall intensity. The physiological demand placed on a player is affected by several other factors, which include tactics, level or importance of game, the opponent, player fitness level, and player/team psychological status and motivation. However, there will always be a certain minimum level of physiological demand placed on a player (Bangsbo, 1995).

### **2.4.1 Demands of Soccer Match-play**

Various researchers have examined the distances covered by outfield players during match-play and authors report various total distances ranging from 3.3 km (Winterbottom, 1952) up to 11.7 km (Whitehead, 1975). Although there is a variety of methods used and results reported, distances of around 8 to 12 km are characteristic of soccer (Reilly and



Thomas, 1976; Ekblom, 1986; Ohashi *et al.*, 1988; Van Gool *et al.*, 1988). It should be noted that the majority of data collection has been carried out using professional players. Nevertheless, Van Gool *et al.* (1988) used Belgian University players who covered a mean distance of 10.3 km during soccer match-play, similar to that covered by professional players in other studies. The large differences in distance recorded by authors are likely to be caused by the differences in methodologies used.

#### **2.4.2 Energy Requirements of Soccer Match-play**

Energy provision for soccer match-play is met through both aerobic and anaerobic energy systems. Various demands are placed on an individual during a soccer game: the majority of activity is at a moderate level dependent upon aerobic energy production, with high intensity bouts interspersed throughout which are dependent upon anaerobic energy production. Determination of energy contribution from the aerobic system has been attempted by measurement of oxygen uptake during match-play. Estimations suggest that more than 90 % of energy produced is from the aerobic energy system (Bangsbo, 1994b). Although the anaerobic system provides energy for 10% or less of total energy consumption, efficiency is essential for production of instantaneous high intensity sprints when required during a game. Direct measurement of oxygen consumption is difficult as the gas collection procedure interferes with normal play and only small periods of a match have been examined (Bangsbo, 1994c). More frequently a player's heart rate is recorded using telemetry and estimations of oxygen consumption may then be made indirectly using an individual's pre-determined HR- $\dot{V}O_2$  relationship.

Mean heart rates during football match-play conditions have been observed at between 155 and 171 beats.min<sup>-1</sup> (Van Gool *et al.*, 1983; Ali and Farrally, 1991; Bangsbo, 1994b), (Van Gool *et al.*, 1988) differences in heart rate becoming evident with different playing



positions (Van Gool *et al.*, 1983) and playing systems (Reilly, 1994). These heart rates correspond to between 66 and 77 % of HR max (Rohde and Espersen, 1988). Rodriguez and Inglesias (1998a) found results within this range for professional players ( $156 \pm 5$  beats.min<sup>-1</sup>) but lower mean heart rate for amateur players at  $148 \pm 19$  beats.min<sup>-1</sup>. Overall average intensity as an estimated percentage of  $\dot{V}O_{2\text{ max}}$  has shown soccer match-play to be approximately 75 % of  $\dot{V}O_{2\text{ max}}$  (Van Gool *et al.*, 1988; Reilly, 1990; Bangsbo, 1994b; Rodriguez and Iglesias, 1998a). However, overestimation of oxygen consumption is a common problem with the technique of HR- $\dot{V}O_2$  estimation utilised (Bangsbo, 1994b; Bangsbo, 1994a). The real relative intensity may be lower due to the heart rate not always reflecting actual  $\dot{V}O_2$  during match-play. It has been claimed that real values during soccer match-play may be lower by as much as 15 % (Rodriguez and Iglesias, 1998a).

Blood lactate concentration is often utilised to indicate the level of anaerobic lactic acid energy production. The concentration of lactate within the blood is lower than the concentration within active muscle (Jacobs and Kaiser, 1982) as it reflects both lactate production and removal (Jordfeldt, 1970; Bangsbo, 1994b). Blood lactate concentration does reflect, albeit underestimate, the production of lactate during exercise. Blood lactate concentrations ranging between 1.6 and 15.5 mmol l<sup>-1</sup> have been reported following match-play (Bangsbo, 1994c) although values around 5 mmol l<sup>-1</sup> appear to be typical. Similar findings have been reported for other forms of intermittent activity of the same intensity (Coggan and Coyle, 1988). Variable intensity activity has been shown to produce higher levels of blood lactate compared to continuous activity of the same overall average intensity (Palmer *et al.*, 1999). A high overall intensity of approximately 85-90% of peak heart rate showed that intermittent activity produced blood lactate levels around



1.5 mmol l<sup>-1</sup> higher than during continuous exercise of the same intensity. As exercise duration continued differences in blood lactate between the two types of activity are increasingly disparate.

### **2.4.3 Metabolic and Fluid Requirements of Soccer Match-play**

Endurance intermittent type sports such as soccer, rely on both aerobic and anaerobic energy provision. Both carbohydrate and fat are therefore major sources of energy. The contribution of each depends upon the intensity of the activity and the fitness level of the player. Protein and amino acids make only a small contribution (<10%) to energy provision during exercise (Lemon, 1987).

The utilisation of muscle glycogen and the glycogenolytic capacity of muscles in a soccer player appear to be important for performance capacity (Hargreaves, 1994; Bangsbo, 1994c; Blomstrand and Saltin, 1999; Rico-Sanz *et al.*, 1999). The synthesis and provision of ATP within active muscle are dependent upon the availability of carbohydrate (McConell *et al.*, 1999). The intensity of exercise in the second half of a soccer match is often lower and this effect may be due to a reduction in available muscle glycogen (Ekblom, 1986) as a result of glycogen utilisation during the first half (Hargreaves, 1994). It therefore follows that if glycogen concentration is enhanced by super compensation strategies at the start of exercise, exercise can be maintained for longer until fatigue forces the cessation of exercise (Rico-Sanz *et al.*, 1999). Games players who drank a carbohydrate-electrolyte solution during prolonged intermittent high intensity exercise showed enhanced exercise capacity. Time to fatigue was delayed by more than 2 min (Nicholas *et al.*, 1995) and when taking carbohydrates during continuous exercise at 70%  $\dot{V}O_{2 \text{ max}}$ , time to fatigue increased by 30% from 152 min to 199 min (McConell *et al.*, 1999).



Ingestion of water with carbohydrate has been shown to produce increases in maximal power to a greater degree than water alone or carbohydrate alone during soccer type intermittent exercise (Fritzsche *et al.*, 2000). Carbohydrate ingestion during physical activity is thought to reduce the demands upon muscle glycogen utilisation (Hargreaves *et al.*, 1984) and increase ATP synthesis within the active muscle (McConnell *et al.*, 1999).

The demands for carbohydrate during match-play can also be met through a high-carbohydrate diet as preparation for intense training and activity (Balsom *et al.*, 1999). A high carbohydrate diet can increase the amounts of muscle glycogen and in turn increase the time to fatigue during exercise. When fed a high carbohydrate diet, players spent a significantly greater amount of time carrying out high intensity manoeuvres compared to others who ate a low carbohydrate diet (Balsom *et al.*, 1999). A lower rating of perceived exertion during exercise has also been found in athletes who ingested carbohydrates compared to individuals who consumed a placebo solution (Utter *et al.*, 1999).

Prolonged bouts of exercise such as those seen during match-play and training have a negative effect upon muscle glycogen availability (Costill *et al.*, 1971). Successive days of prolonged exercise (16.1 km runs) resulted in depleted reserves of muscle glycogen and placed greater demands upon lipid utilisation in order to meet the demands of the activity. As muscle glycogen was reduced with successive runs, plasma free fatty acid concentration increased and lactate production decreased. Thus, the timing and method of carbohydrate intake appear to be important for enabling athletes to carry out necessary intense training and competition (Foster *et al.*, 1979; Coyle, 1991; Friedman *et al.*, 1991). Elite soccer players tend to have heavy schedules of training and match-play and the same emphasis on carbohydrate diet and replacement should be encouraged. Large amounts of muscle glycogen may be depleted and larger amounts of carbohydrate are needed in the



diet to allow for sufficient resynthesis. Players engaged in heavy training and competition schedules may need as much as 10 g of carbohydrate per kg of body mass daily to replenish muscle glycogen fully (Hargreaves, 1991). Eating a carbohydrate rich diet (70%) for 3 days or more prior to prolonged exercise has been shown to delay time to exhaustion by increasing the time taken for muscle glycogen to become critical (Bosch *et al.*, 1993).

Free fatty acids, termed non-esterified fatty acids (NEFA), also contribute to metabolism (Ahlborg *et al.*, 1974) and have been shown to increase during exercise at a moderate intensity of approximately 60%  $\dot{V}O_{2\text{ max}}$  (Tsetsonis and Hardman, 1995). This contribution represents either increased mobilisation of fatty acids from adipose tissue or a reduction in uptake in the liver. When exercise is prolonged or strenuous, the blood flow to splanchnic tissues such as the liver is reduced. This reduction impacts on liver NEFA uptake and there is a concomitant reduction in triacylglycerol (TAG) formation. The concentration of TAG is directly attributable to exercise intensity with greater reductions during moderate intensity exercise compared to low intensity exercise (Tsetsonis and Hardman, 1995). During less intense periods of intermittent activity, circulating free fatty acids and triglycerides rather than intra-muscular lipids primarily contribute to the energy utilised (Rico-Sanz *et al.*, 1998). During higher intensity periods of activity, fat oxidation falls while the contribution of carbohydrate metabolism rises (Christmass *et al.*, 1999a). When substrate oxidation is compared between intermittent activity and continuous activity of the same overall oxygen consumption, fat oxidation is reduced and carbohydrate oxidation is increased with higher concentrations of blood lactate following the intermittent exercise (Christmass *et al.*, 1999b). These studies by Christmass *et al.* (1999a; 1999b) also showed that NEFA concentration increased with the



duration of exercise; however, the concentrations of NEFA were not different between continuous and intermittent activity.

Fluid replacement plays an important role in the maintenance of soccer performance. Even if the weather conditions are cool there will be a significant fluid loss through sweating (Maughan and Leiper, 1994) due to the high intensity nature of the soccer activity and even mild dehydration can produce significantly reduced performance. Fluid intake in the form of a carbohydrate-electrolyte drink is the best method of rehydration (Fritzsche *et al.*, 2000) as fluid levels and carbohydrate stores are replenished simultaneously. The use of intravenous rehydration has been utilised by some athletes as an ergogenic aid to rehydrate rapidly and improve subsequent performance but recent research has established that oral rehydration results in less physiological strain and increased time to exhaustion compared to intravenous rehydration (Casa *et al.*, 2000). The main differences between oral and intravenous rehydration is reduced core temperature during exercise with oral rehydration (Montain and Coyle, 1992; Casa *et al.*, 2000). Reduced core temperature during oral rehydration affects cardiovascular responses resulting in lower heart rate and higher stroke volume than intravenous rehydration. Although intravenous delivery restored plasma volume more rapidly than oral delivery, the effect on core temperature was more dramatic when fluid was delivered orally (Casa *et al.*, 2000). As already discussed, the exercise intensity of soccer has been estimated at an overall 75% of  $\dot{V}O_{2\text{ max}}$  during 90 min of match-play. This intensity of exercise for the duration of 90 min will place great demands on the thermoregulatory system and the main cooling mechanism of sweating in turn causes significant levels of dehydration. Exercise performance is significantly reduced if an individual is dehydrated as little as 2% and losses as great as 5% may reduce performance by up to 30% (Saltin and Costill, 1988). In



hot environmental conditions the requirements for cooling are increased, thereby placing further demands on body cooling.

#### **2.4.4 Thermoregulation and Environment during Soccer Match-play**

The higher physiological demands during intermittent exercise compared to continuous exercise of the same overall work-load (Cable and Bullock, 1995; Purvis and Cable, 1999) invariably associate soccer with large metabolic heat production. Very little research has been performed looking specifically at soccer performance from a thermoregulatory viewpoint. Nevertheless, work that has been completed (Ekblom, 1986) has been conclusive in demonstrating a reduction in performance during soccer match-play in a warm environment ( $>30^{\circ}\text{C}$ ). Ekblom (1986) performed motion analysis and reported the overall distance covered during match-play was reduced by approximately 55% in a hot environment ( $30^{\circ}\text{C}$ ) compared to a cooler environment ( $20^{\circ}\text{C}$ ). Rise in core temperature reached  $39.5^{\circ}\text{C}$  following match-play in elite (first-division) soccer players, slightly lower core temperatures were observed in the three lower division players ( $39.2^{\circ}\text{C}$ ,  $39.0^{\circ}\text{C}$  and  $39.1^{\circ}\text{C}$ ). Core temperatures at  $39.0^{\circ}\text{C}$  and above will adversely affect soccer performance (Reilly, 1996a) and any method that delay or slow the increase in core temperature will increase the time to exhaustion.

A comprehensive study (Galloway and Maughan, 1997) at an exercise intensity similar to that found from soccer match-play ( $70\% \dot{V}\text{O}_{2\text{ max}}$ ) reported the time to exhaustion on different environmental conditions and demonstrated the effect of core temperature on development of fatigue. Core temperature as a critical factor of fatigue and not circulatory stress, was reported by Nielsen *et al.* (Nielsen *et al.*, 1993). Intermittent exercise and continuous exercise at the same workload have been compared and intermittent exercise was reported to be more physiologically demanding (Cable and



Bullock, 1995). From the work of Galloway and Maughan (1997) and Cable and Bullock (1995) it follows that soccer activity in a hot environment will be more physiologically and thermally demanding than similar steady-state activity or activity at a lower ambient temperature, resulting in a quicker time to fatigue.

Rowell (1974) and Roberts and Wenger (1979) recognised that even in a neutral environment, the cutaneous circulation is attenuated during high intensity anaerobic exercise. When additional environmental demands accompany high intensity exercise, blood supply to the muscles may be compromised and hence exercise intensity reduced to allow cooling to take place. The extra demands on cardiac output are reflected by the shorter distance covered during soccer play in a hot environment (Ekblom, 1986) and reduced performance in intermittent supramaximal running in a hot and humid environment (Maxwell *et al.*, 1996).

Time to exhaustion during intermittent exercise is reduced compared to continuous exercise of the same mean power output in both warm (35°C) and cool environments (10°C) (Nevill *et al.*, 1995). Aural temperature, rectal temperature, heart rate, oxygen consumption and blood lactate concentration were all found to be elevated following intermittent exercise in both warm and cool conditions. Intermittent exercise provides a greater thermal strain compared to continuous activity of the same overall workload (Cable and Bullock, 1995; Nevill *et al.*, 1995; Purvis and Cable, 1999).

Morris *et al.* (1998) conducted a study that utilised a protocol designed to simulate field games such as soccer, hockey and rugby. Although this protocol was limited due to general nature of the activity pattern, common to as many intermittent protocols, a significantly reduced performance was found in a hot environment (~30°C, ~66% RH) compared to a moderate environment (~20°C, ~71%RH), which may be comparable with



actual soccer activity. The reduction in performance was quantified at 21% lower in the hot environment for all subjects. For subjects who were unable to complete the hot trial, the reduction in performance was closer to 40%. Several variables were considered and no significant differences were found for body mass, plasma volume change, rating of perceived exertion, blood glucose, plasma free fatty acid, blood lactate or plasma ammonia concentrations during the two environmental trials. Conversely, rectal temperature was  $39.4 \pm 0.1^{\circ}\text{C}$  and  $38.9 \pm 0.1^{\circ}\text{C}$  ( $P < 0.01$ ) in the hot vs. moderate trial, respectively, leading the researchers to conclude that rectal temperature appeared to be an important factor in the termination of exercise in the hot trial.

Observations of sweating in the same study indicated that the individuals who showed increased sweating were able to exercise longer in the hot environment. The early onset of sweat production is an indication of good thermoregulatory control and the data from Morris *et al.* (1998) supported this view.

Training of individuals is an important factor in tolerance of hot environments (Pandolf, 1979; Aoyagi *et al.*, 1997). The seven individuals of the study who tolerated the hot condition well took part in endurance training at least three times a week whereas the five individuals who were unable to complete the hot trial participated in sprint and strength training. It is well known that physical training in a cool environment serves to acclimatise the individual to exercise in the heat due to the elevation of core temperature and improve the sweating response (Roberts *et al.*, 1977; Kenney and Johnson, 1992).

Fluid replacement strategies during soccer match-play to compensate for the effects of dehydration will slow the increase in core temperature. Mustafa and Mahmoud (1979) reported fluid losses of 3% body mass during soccer match-play at approximately  $30^{\circ}\text{C}$ , 40% relative humidity. Davies *et al.* (Davies *et al.*, 1995) observed English Premier



League soccer players over a period of month in the winter ( $< 10^{\circ}\text{C}$ ) and reported that reductions of between 1.1% and 3.9% body mass ( $\bar{x} = 2.9 \pm 0.6\%$ ) would have occurred if fluid replacement had been prohibited. Dehydration greater than 1% body mass is a significant level of dehydration, which will contribute to elevated core temperature and cardiovascular strain (Hoffman *et al.*, 1994).

A study by Drust *et al.* (Drust *et al.*, 2000) investigated the effects of pre-cooling focussed on the physiological responses to soccer-specific intermittent exercise. In contrast to other, less specific, pre-cooling studies (Booth *et al.*, 1997; González-Alonso *et al.*, 1999) no evidence was found to support any benefit to pre-cooling for soccer activity in a moderately warm environment of  $26^{\circ}\text{C}$ . The pre-cooling procedure used in the study by Drust *et al.* (2000) resulted in a very small reduction in core temperature of only  $0.3^{\circ}\text{C}$ . Booth *et al.* (1997) concluded the pre-cooling procedure with a mean core temperature reduction of  $0.7^{\circ}\text{C}$ , which resulted in improvements in running performance in a warm environment ( $32^{\circ}\text{C}$ ). González-Alonso *et al.* (1999) also demonstrated that if starting core temperature is lower, time to exhaustion is increased due to fatigue always occurring at the same core temperature. A lower starting core temperature delays the time to reaching the critical core temperature and fatigue and a strong inverse relationship between time to exhaustion and initial body temperature was shown (González-Alonso *et al.*, 1999). If the core temperatures of individuals in the Drust *et al.*'s (2000) study had been further cooled, some benefits for pre-cooling and soccer-specific intermittent activity may have resulted.

Soccer in the United Kingdom is played throughout the year with the English Football Association's and national Premier League games played between August and May, including the British winter months, predominantly December to February. The



environmental temperature range over these months is approximately 0°C to 15°C. Under these conditions the physiological performance of a soccer player may be adversely affected (Cable, 1999) as even mild cooling at ambient temperatures of below 20°C reduce muscular performance compared to 27°C (Oksa *et al.*, 1996).

Galloway and Maughan (1997) found that individuals exercising at 70%  $\dot{V}O_{2\max}$  in 4°C reached exhaustion earlier than when the same exercise was performed in environmental conditions of 11°C. Although an environment of 11°C would be considered as cold in much of the literature, Galloway and Maughan (1997) found this was the optimal condition, with exhaustion occurring at approximately 93 min compared to the same exercise in environments of 4°C (81 min), 21°C (81 min) and 31°C (51 min). The time to exhaustion is a relevant point to note in that the exercise intensity is comparable to soccer activity at 70%  $\dot{V}O_{2\max}$ , only exercise in the coolest environment equalled the duration of a soccer match, the other ambient temperatures all causing exhaustion less than 90 min.

Periods of low activity following a high activity bout during soccer match-play may constitute a risk for excess heat loss. Following intense exercise tissue insulation is reduced due to cutaneous vasodilation. Therefore, body heat is lost readily to the environment and given that metabolic heat production is reduced, core temperature falls (Young *et al.*, 1999). Excessive heat loss following high activity in a cool environment may be of particular concern to goalkeepers who characteristically have a lower overall physiological demand during match-play, but are required to produce periods of high activity, which may be followed by latent periods (Reilly and Thomas, 1976).

Cumulative days of activity in cold and wet environmental conditions appear to induce fatigue of the thermoregulatory system, exhibited as a reduction in core temperature due to greater peripheral heat loss (Castellani *et al.*, 1999). Such effects may have



ramifications for the heavy training and match-play schedule followed by elite soccer players.

## 2.5 CLOTHING

Thermal balance is achieved when heat loss is equivalent to heat gain and may be altered by factors that influence the rate of heat dissipation to the ambient environment. An important factor to consider is clothing which acts as a barrier between the human body and ambient air. The wearing of clothing causes an increase in local skin temperature, mean skin temperature and skin blood flow (Hirata, 1988). Heat loss by means of convection and evaporation is impeded due to the creation of a microenvironment close to the surface of the skin dissimilar to the ambient environment (Sullivan and Mekjavic, 1992; 1994a; Pascoe *et al.*, 1994b). Clothing creates specific dynamic thermal properties altering the microenvironment, including the following parameters:

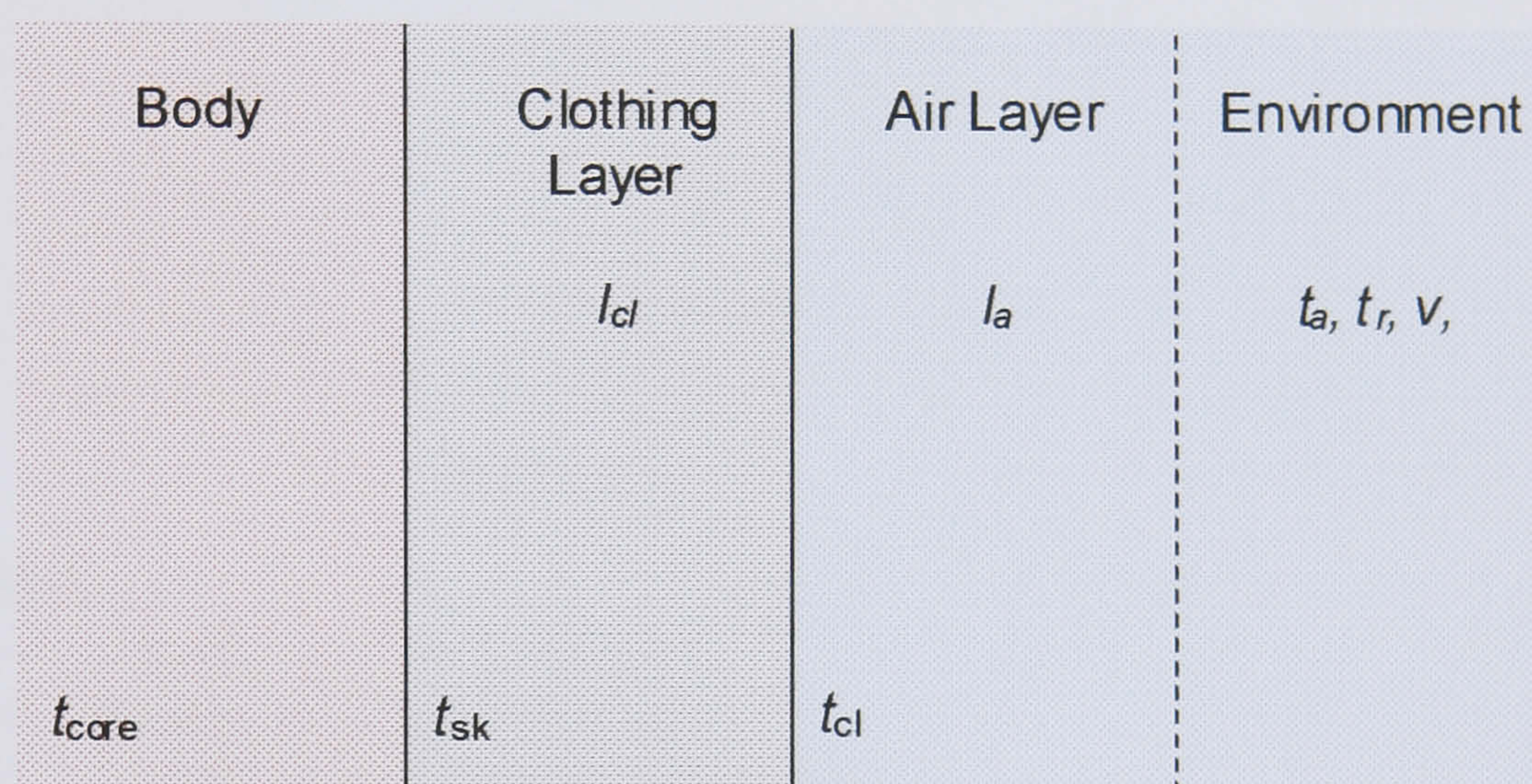
- Heat exchange (radiation, convection, conduction, evaporation), (Havenith, 1999)
- Dry insulation (clo), (Havenith *et al.*, 1990b)
- Vapour and moisture transfer/accumulation (Woodcock, 1962; Havenith *et al.*, 1990a; Ha *et al.*, 1996)
- Clothing fit (Brownlie *et al.*, 1987; Bouskill *et al.*, 1998b)
- Effects of wind and air movement within layers (Danielsson and Bergh, 1996; Bouskill *et al.*, 1998a; Parsons *et al.*, 1999)
- Effects of multiple clothing layers (Hong *et al.*, 1993; Chen *et al.*, 1996; Havenith, 1999)
- Posture and movement of wearer (Havenith *et al.*, 1990a; Holmér, 1995)

### 2.5.1 Heat Balance and Clothing

Heat balance accounts for the change in energy transfer between a human and the environment. For the human body to maintain thermal equilibrium with the surroundings



heat flows from the core to the skin, through the clothing layer, air layer and into the ambient environment (Pascoe *et al.*, 1994a; Pascoe *et al.*, 1994b). The flow of heat is fundamentally dependent upon the insulative characteristics of the clothing worn as interactions between core, skin and clothing influence heat transfer. Figure 2.6 illustrates the basic concept of a human body / clothing model for heat exchange.



Where:

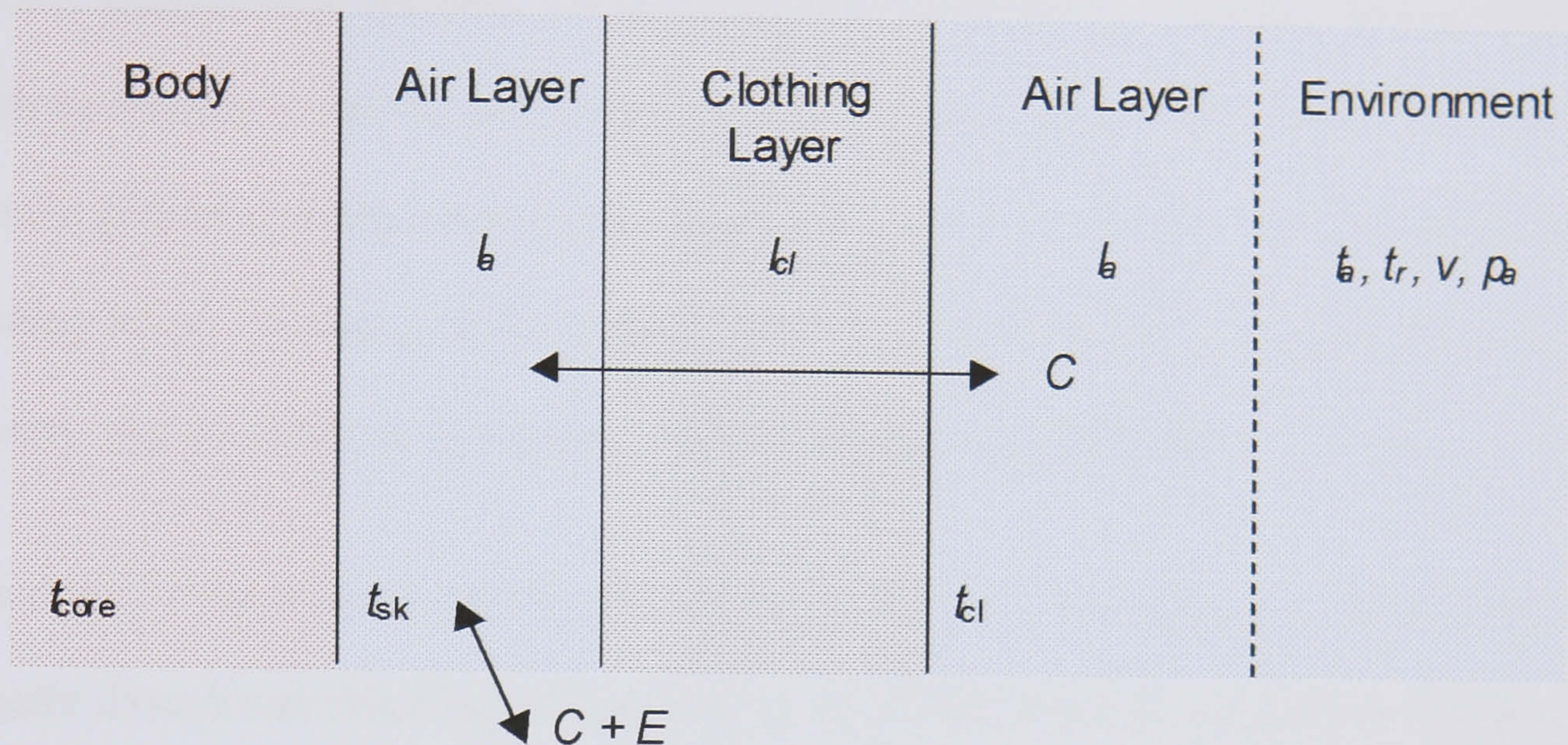
- $t_{core}$  = body core temperature
- $t_{sk}$  = body skin temperature
- $t_{cl}$  = clothing surface temperature
- $l_{cl}$  = intrinsic clothing insulation
- $l_a$  = air layer insulation
- $t_a$  = mean ambient temperature
- $t_r$  = mean radiant temperature
- $v$  = mean air velocity

**Figure 2.6.** A simple thermal clothing model of a human body.  
Redrawn from Parsons (1993).

The model illustrates the effects of the clothing as an insulative layer. The presence of the air layer directly in contact with the clothing surface allows for extra insulation and ensures that the clothing surface temperature ( $t_{cl}$ ) is higher than the environmental temperature ( $t_a$ ). However, the presence of clothing is usually more complex as a



micro-environment is also trapped between the skin and the clothing layer (Figure 2.7), adding an additional insulation factor.



Where:

- $t_{core}$  = body core temperature
- $t_{sk}$  = body skin temperature
- $t_{cl}$  = clothing surface temperature
- $l_{cl}$  = intrinsic clothing insulation
- $l_a$  = air layer insulation
- $t_a$  = mean ambient temperature
- $t_r$  = mean radiant temperature
- $v$  = mean air velocity
- $C$  = convective heat loss
- $E$  = evaporative heat loss

**Figure 2.7.** A clothing / air layer thermal clothing model of a human body.  
Redrawn from Parsons (1993).

The insulative properties of a clothing layer change with alterations in several factors; clothing coverage (clothing area factor) (Holmér *et al.*, 1999), fabric type (Brownlie *et al.*, 1987), motion/posture (Holmér, 1985; McCullough, 1993) and fit (McCullough *et al.*, 1983; Kakitsuba *et al.*, 1987). Where a fabric is designed to fit closely and wick sweat away from the skin surface, the internal air layer becomes extremely narrow and the clothing layer incorporates layers of liquid and vapour. Sweat passes through the clothing and the heat of vaporisation occurs within the clothing layer and not the skin (Parsons,



1993). The consequences are a reduction in sweating efficiency and an increase in thermal demand. Condensation of water vapour within clothing will not only release latent heat but also displace air from the clothing layer and reduce resistance to dry heat transfer (Haslam and Parsons, 1988), which may contribute to heat loss. Looser fitting clothing has lower intrinsic insulation than tight fitting garments (Kakitsuba *et al.*, 1987) due the greater clothing microenvironment allowing for greater air movement within the clothing layer. Pumping of air through vents in garments, such as through the end of sleeves, also increases air movement influencing insulation (Parsons *et al.*, 1999).

The rate of evaporation from the skin surface is likely to be linked to the rate of vapour transfer through a clothing layer (Kakitsuba *et al.*, 1988) with the permeability of a fabric significantly correlated to evaporative heat loss from the skin (Nishi and Gagge, 1970). Fabrics with "breathable" qualities allow for further complex heat exchange mechanisms as air moves between pores in the fabric contributing to a lower evaporative resistance ( $R_e$ ) than for other less permeable fabrics (Holmér and Elnäs, 1981; Oohori *et al.*, 1988). Air exchange from the clothing microenvironment to the ambient air is increased and evaporative cooling is facilitated (Bouskill, 1999) resulting in a lower core temperature, skin temperature, reduced weight loss due to sweating and prolonged time to exhaustion compared to impermeable fabrics (Holmér and Elnäs, 1981; Holmér, 1995).

Sullivan and Mekjavic (1992) tested the effects of suit design and fabric composition and illustrated the importance of considering the microenvironment created by clothing assemblies. The suits examined were designed to provide thermal protection for military helicopter personnel without impairing performance. The authors postulated that vapour pressure and relative humidity within a clothing microenvironment were determining factors in the heat stress imposed. The suit that exhibited the highest levels of humidity



and vapour pressure within the clothing microenvironment caused the greatest elevation in core temperature and skin temperature. Evaporation of sweat from the skin into the ambient environment represents the most efficient cooling route and can be greatly reduced by certain clothing materials and their effects on air movement and vapour pressure gradients between the skin, clothing and environment (Berglund and Gonzalez, 1977; Tokura and Midorkikawa-Tsurutani, 1985).

Loose fitting clothing which may have the same effective insulation as a tight fitting garment, will have a lower intrinsic insulation when worn due to increased air movement within the clothing microenvironment (Kakitsuba *et al.*, 1987). Additionally, clothing ensemble coverage is a linear function of intrinsic clothing insulation (Kakitsuba *et al.*, 1987). The permeability of clothing is increased with loose fitting clothing, as increased wind and air movement causes a reduction in vapour resistance (Havenith *et al.*, 1990a), resulting in a reduced heat strain. Movement and posture significantly alter the total clothing insulation while wind primarily only affects the insulation of the surface air layer (Havenith *et al.*, 1990b). During walking, cycling or running, overall insulation may be reduced by as much as 60% from a resting state (Holmér, 1985; Nielsen *et al.*, 1985) and surface air insulation increases by up to 25% when changing to a seated position from a standing position. Insulation decreases when changing from a standing position by up to 25% when cycling and up to 50% during walking (Nielsen *et al.*, 1985). Increased air movement does not influence intrinsic insulation during walking but decreases insulation by 18% when in the standing posture, and surface insulation was falls by up to 50% during activity (Nielsen *et al.*, 1985). Movement significantly affects evaporative resistance. When changing from walking to running evaporative resistance is reduced by 70% when wearing wool fabrics and by 80% when wearing nylon fabrics (Nielsen *et al.*, 1985).



Multiple clothing layers further complicate heat and vapour transfer away from the skin surface (Hong *et al.*, 1993). Vapour pressure is highest between the skin and surface of the inner clothing layer, falling through successive layers with each layer possessing different heat transfer characteristics. Clothing with higher vapour resistance causes an increase in skin wettedness which in turn increases thermal discomfort (Hoeppe *et al.*, 1985) and highly hygroscopic fibres such as wool feel drier and more comfortable than less absorbent materials such as polyester (Li *et al.*, 1993). Additionally, the vapour resistance of clothing has been observed to be less during exercise compared to a rest period. This effect is likely to be due to the bellows effect of clothing movement (Hoeppe *et al.*, 1985; Bouskill *et al.*, 1998b) increasing ventilation; decreasing insulation and vapour resistance. Temperature and humidity of a clothing microenvironment during walking were observed to increase rapidly if walking were paused due to the cessation of the "bellows" ventilation effect on clothing during movement (Vokac *et al.*, 1971).

### **2.5.2 Clothing in Warm Environments**

Heat transfer depends on the interactions between core, skin and clothing. Pascoe (1994a; 1994b) outlined the complications that clothing presents to heat dissipation. The transfer of heat from the clothed body to the surroundings can be further complicated by unfavourable environmental conditions, especially hot and humid conditions where sweat evaporation is attenuated, resulting in an increased core and skin temperature. Sportswear may be considered a barrier to evaporation of sweat and hence the dissipation of heat. Sweat, and consequently skin wettedness, is an important factor in thermal comfort (Nielsen and Endrusick, 1990). When impermeable clothing is worn the evaporation of sweat is partially or totally restricted. The obstruction of evaporative cooling causes the storage of heat and elevation of core body temperature.



Fabrics possess differing physical properties affecting moisture and water absorbency. Research has shown that the property of a fabric to absorb moisture has physiological influences for sweating mechanisms and clothing comfort (Nishi and Gagge, 1970; Kim, 1999). It has been shown that subjects wearing good moisture absorbing fabrics lose less body weight (hence less sweat) (Tokura and Midorkikawa-Tsurutani, 1985) and have lower core temperatures (Ha *et al.*, 1995) than subjects wearing poor moisture absorbing materials. The more moisture a fabric can absorb the lower the insulation of that garment (Ha *et al.*, 1995) with the insulation of wet fabrics approximately 15% lower than dry fabrics (Holmér, 1985), reflected by a lower skin temperature when wearing a hygroscopic fabric compared to a less absorptive material (Tokura and Midorkikawa-Tsurutani, 1985). Kwon *et al.* (1998) found similar results but produced a much more comprehensive study with conclusive results: three fabrics were examined, comprising a wool and cotton blend with high moisture absorbency, cotton with medium moisture absorbency and polyester with low moisture absorbency. Core temperature was significantly lower for the hydrophilic fabric when air velocity was  $1.5 \text{ m s}^{-1}$ . For conditions with and without wind, the wool and cotton blend (most hydrophilic i.e. absorbing the greatest amount of water) clothing microclimate temperature and resultant heart rate were lower. Total sweat production was measured for each clothing fabric and the least amount of sweat produced resulted when wearing the wool and cotton (high water absorbency) material. Change in clothing mass was also measured for each clothing ensemble. The increase in mass was greatest for the most hydrophilic material and lowest for the least absorbent. Therefore the hydrophilic properties of the fabrics were of physiological importance in reducing heat stress especially under conditions of higher air velocity.



The majority of clothing science research and development has concentrated on protective clothing and aspects of health and safety in industrial settings (Nunneley, 1988). The clothing must be designed to protect the individual from environmental hazards, e.g. fire-fighters and furnace workers, without causing unacceptable heat stress or impede work performance (Sen, 1993; Montain *et al.*, 1994; Parsons, 1999). Many computer models have been formulated as tools for estimating the risks from clothing, exercise and climate (Parsons, 1995) and can suggest a 'zone' of conditions under which a clothing ensemble is suitable for wear. Ergonomically designed clothing has been observed to reduce heat stress and physiological demands compared to traditional work wear (Sen, 1993). Improvements in ventilation and vapour permeability, while still retaining flame-retardant and radiant heat reflection properties ensured that heart rate and body temperature were reduced. Comfort was also improved by up to 4-fold suggesting that use of such a garment would increase productivity, and illustrates the effects of clothing choice on thermoregulation. Vapour transfer properties are an important consideration in the characteristics of protective clothing ensembles and as such have been widely researched in the context of heat stress protection, risk assessment and international standards (Holmér, 1999; Parsons *et al.*, 1999; Barker *et al.*, 1999). Evaporative heat losses have been defined as determined by the permeability of the clothing layer(s) further complicated by vapour condensation and ventilation of the clothing microclimate (Holmér, 1995).

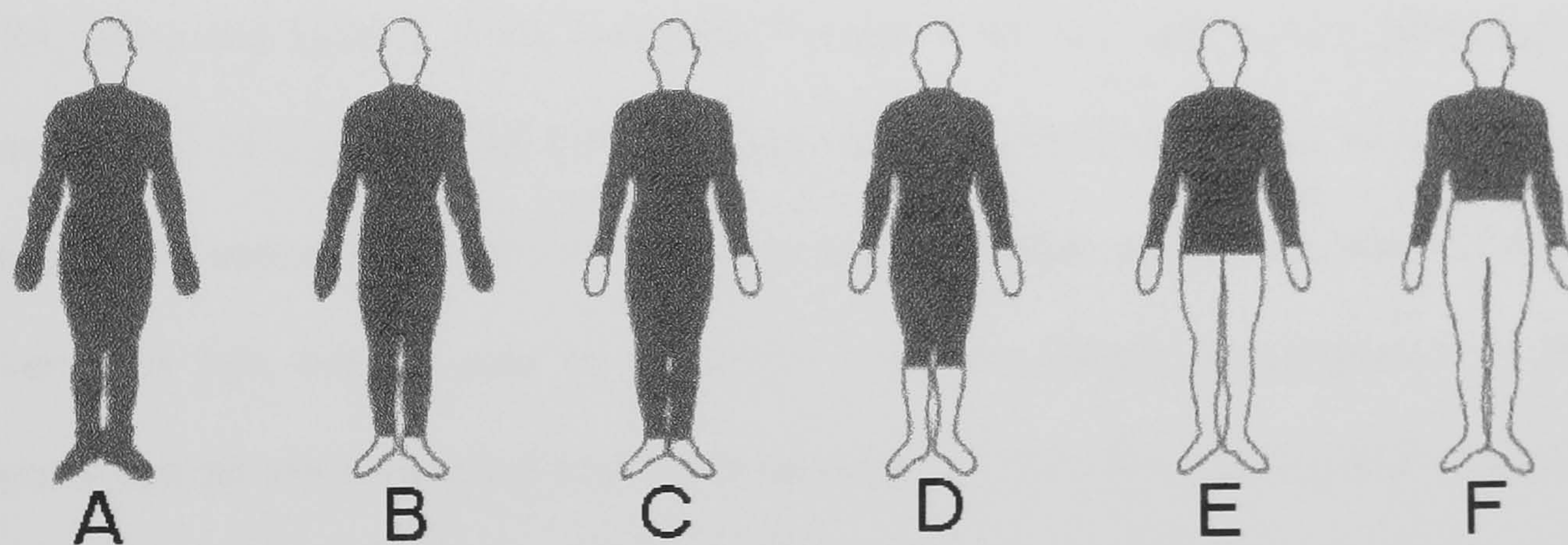
The effects of exercise on core temperature consider that workload is the determining factor rather than the environmental conditions within a "prescriptive zone". (Smolander *et al.*, 1991; Sawka *et al.*, 1996; Franks *et al.*, 1996; Moran *et al.*, 1996). However, certain clothing may create a hot and humid microenvironment, which is above the prescriptive zone, hence increasing core temperature (Kenny *et al.*, 1999). The



contribution of sportswear to thermoregulation has been shown from studies comparing two fabrics in different regions of the body (Denoth *et al.*, 1993), and comparing different types of athletic racing apparel (Brownlie *et al.*, 1987). It was shown that the choice of sportswear garment can have a significant influence on physiological and thermoregulatory responses such as heart rate, core temperature and sweat production (Brownlie *et al.*, 1987; Denoth *et al.*, 1993). In contrast, other research examining fabric types have not shown any effects on thermal responses such as sweating onset and core temperature (Galbraith *et al.*, 1962).

### 2.5.3 Clothing in Cold Environments

The role of clothing is also important as a protective barrier against a cold environment. Lee and Tokura (1998) performed a comprehensive two-part study on clothing coverage during resting conditions at 10°C. The 6 clothing configurations, A - F are illustrated in Figure 2.8.



**Figure 2.8.** Illustration of clothing ensemble coverage in Lee and Tokura's research (1998).

The first part of the study examined the physiological responses to ensembles A - C, looking especially at the thermoregulation mechanisms of the extremities; and the second part of the study examined the physiological responses to ensembles C - F. Comparisons of ensembles A - C showed the highest core temperature ( $T_r$ ) resulted when wearing



ensemble C while the highest skin temperature ( $\bar{T}_{sk}$ ) was measured when wearing ensemble A. When the extremities are uncovered, the blood tends to be returned to the core through deeper veins to prevent heat loss, this results in a higher core temperature. Conversely, when the extremities are covered the blood flow return is through more peripheral vasculature allowing more heat loss to the surrounding environment. Clothing of the extremities is discussed in more detail below.

The second part of Lee and Tokura's (1998) study found that reduction in rectal temperature was progressively less through ensembles C, D and E, but ensemble F resulted in the greatest reduction in core temperature compared to the other three ensembles. Change in rectal temperature at the end of exercise was approximately +0.09°C for ensemble E, -0.01°C for ensemble D, -0.19°C for ensemble C and -0.24°C for ensemble F. The disparity between the two ensemble of least coverage (E and F) is surprising and the authors suggest this is due to a mechanism termed as the "counter-current heat exchange system" (Jeong and Tokura, 1988; Jeong and Tokura, 1989; Jeong and Tokura, 1993; Jeong and Tokura, 1995; Lee and Tokura, 1998) and is characterised by a preferential venous return via the surface vasculature when clothing insulates the entire body and venous return through deeper vasculature when clothing coverage is less, even in cold environments. The physiological consequences of the counter-current mechanism is a lower core temperature when fully clothed as in ensemble A and a higher core temperature when less clothed such as ensembles B to E. Ensemble F shows a different response, probably as the buttock and hypogastric regions (only covered by thin briefs) are considered as part of the core in the core-shell division (Xu and Werner, 1997; Lee and Tokura, 1998).



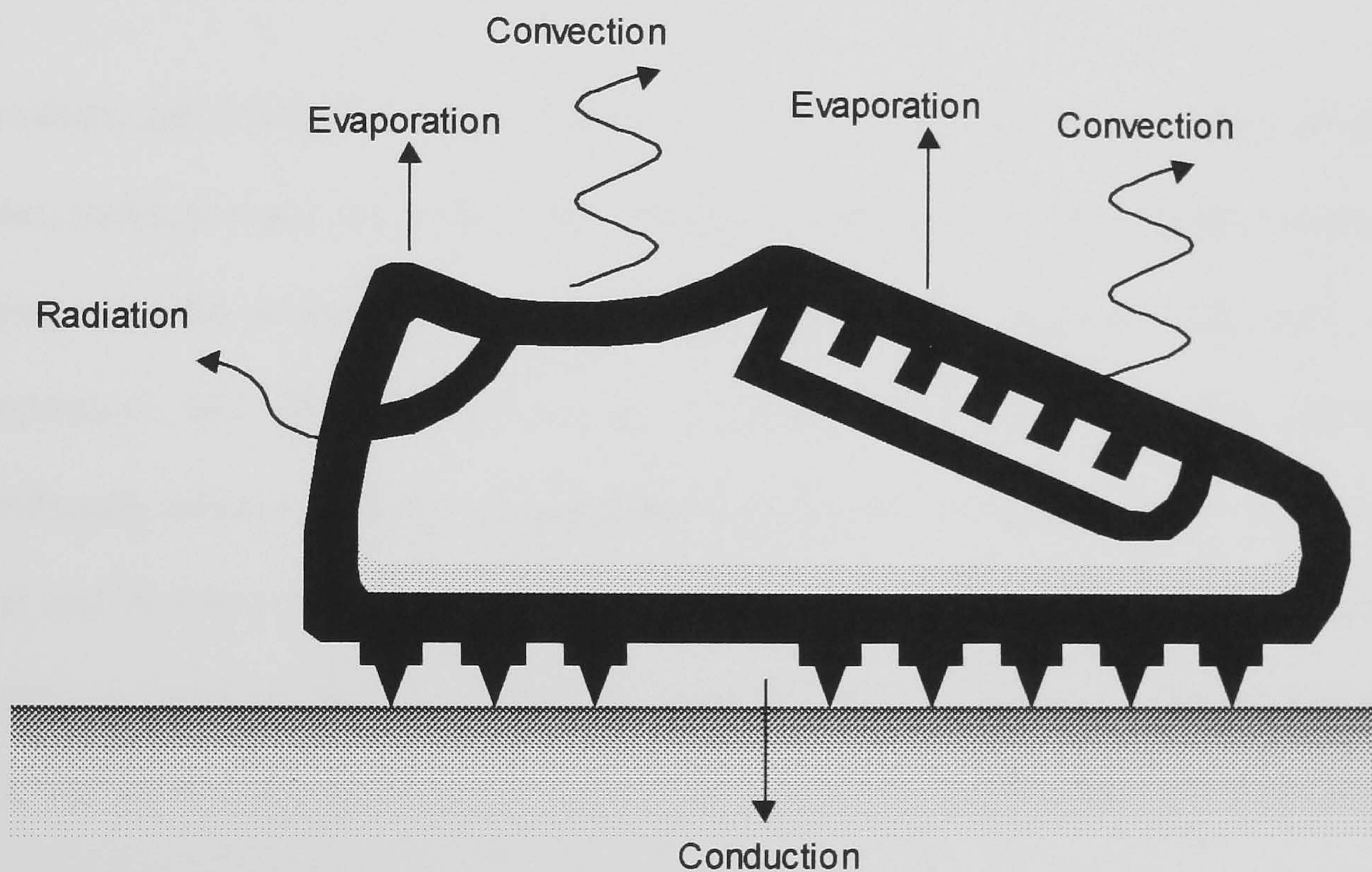
Nielsen and Endrusick (1988) observed no significant differences between core temperature, skin temperature, skin wettedness or sweating onset when wearing underwear of five different fibre compositions during intermittent activity in the cold (5°C). A later study by Nielsen and Endrusick (1990), using the same experimental conditions, commented on the significant differences in the sensation of wettedness, while skin temperature was not perceived as different between the underwear conditions. Illustrating the strong relationship between thermal comfort and skin wettedness that has been observed in warmer environments (Winslow *et al.*, 1937; Winslow *et al.*, 1939).

#### **2.5.4 Clothing of the Extremities**

Jeong and Tokura (1989; 1993) examined two clothing ensembles with different coverage of the body in conditions of heat stress, in a similar research design to the study discussed earlier (Lee and Tokura, 1998) which examined the effect of clothing coverage in conditions of cold stress. Coverage of all of the body with exception of the head (Ensemble A in Figure 2.8) caused a significantly greater core and skin temperature compared to the same fabric covering most the body but not head, hands or feet (Ensemble C in Figure 2.8). One of the most interesting observations was that rectal temperature decreased much more quickly following exercise in the total coverage garment (A) than the garment not covering the head, hands and feet (C), despite the higher insulation in garment A. However, skin temperature of the hands and feet did not fall as quickly in garment A compared to garment C, suggesting that peripheral vasodilation in A contributed to a greater heat exchange resulting in a faster reduction in core temperature during recovery (Jeong and Tokura, 1989; 1993). The findings suggest there is a significant role of the extremities in the mechanisms of thermoregulation.



Footwear, such as a soccer boot (Figure 2.9), allows for heat losses by means of conduction through the soles into the ground, convection and radiation from the surfaces, convection from the openings at the ankles and lacing area, and evaporation through the material and openings. However, these avenues for heat loss are minimal and shoes generally prevent the circulation of air around the foot resulting in a reduction in heat loss. It has been suggested that the thermal state of the extremities may alter core temperature (Jeong and Tokura, 1993).



**Figure 2.9.** Avenues of heat loss through footwear. Adapted from Bergquist and Holmér (1997)

Ponsonby *et al.* (1979) utilised the methods of thermography to study the thermal responses of the feet following exercise in sports shoes. Metal studded shoes produced a change in temperature of up to  $5.5^{\circ}\text{C}$ , which lasted for 25 min after the end of exercise, compared to a rise of up to  $1.5^{\circ}\text{C}$  lasting only 10 min for the un-shod foot. Moulded studded shoes and nylon studded shoes produced rises of up to  $3^{\circ}\text{C}$  each, lasting for 10 and 25 min, respectively. Similarly, Ring *et al.* (1995) measured greater increases 15 min post-exercise for a metal stud,  $2.59^{\circ}\text{C}$  and  $1.69^{\circ}\text{C}$ , compared to a plastic stud,  $0.80^{\circ}\text{C}$  and



0.62°C, in the metatarsal and heel areas of the foot, respectively. A gradual increase in blood flow in the 15 min post-exercise was localised to areas impacted by the studs was observed on thermographic images. The results suggested that use of plastic studded sports shoes may cause less mechanical damage and subsequent injury. An additional observation by Ponsonby (1979) was differences in temperature between the dominant and non-dominant feet with the dominant foot producing a greater temperature of between 0.2°C and 1.5°C. An explanation for this effect may be the larger muscle bulk and more efficient blood supply on the dominant side (Ponsonby *et al.*, 1979).

Kawabata and Tokura (1993) performed experiments using two different types of sports shoes; standard shoes and mesh shoes. The thermoregulatory and physiological responses during rest and walking were measured and results were striking; heart rate, core temperature and skin temperatures in all areas off the body and feet increased significantly when wearing the standard shoes compared to the mesh shoes. In contrast, Lees and Thornley (1990) examined two types of training shoe during 40 min of treadmill running, a standard shoe and a modified shoe with an air circulation system. The shoe with the air circulation system produced no benefits in reducing the build up of heat within the running shoe.

Bergquist and Holmér (1997) performed experimental work investigating insulation of the foot with a simulated moving leg and foot. Different footwear was examined under different conditions of movement, load and footwear size. Reduction of insulation was found to be the most significant ( $P < 0.001$ ) changing from resting to running, resulting in an average reduction of 13% across the five sets of footwear examined.

Various sock materials were assessed by Davis (1975). His summary conclusions were that there were distinct differences in wicking ability between the sock materials and



although thinner socks kept the feet cooler and drier, thicker socks were preferred for comfort by the participants. Morris *et al.* (1984-1985) also examined the effects of hydrophilic and hydrophobic sock fibres and fabric properties on comfort, but found no appreciable differences to allow prediction of comfort. Perceived foot dryness and sock softness were the only significant parameters for comfort, however, these measures were not necessarily related to the moisture absorption characteristics of the fabrics. In contrast, a wicking fibre, in this case a synthetic fibre, Orlon<sup>®</sup>, into a sock, was generally perceived as being more comfortable by wearers compared with socks composed of natural wool or cotton fibres (Pontrelli, 1977). The Orlon<sup>®</sup> socks kept the feet drier and the fibres felt subjectively softer. The fibres were more resistant to moisture accumulation than the natural fibres wicking sweat away from the skin at a faster rate than the natural fibres where sweat tended to be retained (Pontrelli, 1977). The increased wicking allowed more sweat to be transported to the shoe where evaporation could occur; however, no differences in maximum foot skin temperatures were reported (Pontrelli, 1977).

The effect of cooling the feet in order to prevent heat strain was evaluated by Livingstone *et al.* (Livingstone *et al.*, 1995) and they calculated that between 55 W and 155 W of heat was removed from the body by immersing the feet in a cold water bath. Heat loss of this quantity was exhibited as decreased skin temperature and a slower rate of increase of core temperature resulting in increased time till onset of fatigue. Blood flow circulating through the vasculature of the foot is cooled and the cooled blood returns to the core affecting a reduction in the core temperature of the body. Livingstone *et al.* also published research that investigated heat loss when immersing the hands in water (Livingstone *et al.*, 1989) and found similar results to when immersing feet. Heat loss



was measured at between 31 W and 124 W, and again the amount of heat lost was sufficient to reduce both skin and core temperatures.

Very little published research is available examining the thermal responses of the hands during exercise in different conditions of environment or clothing worn. Protection of the hands is of particular concern in conditions of cold exposure. The majority of research has been concentrated on examination of response of the hands to extreme cold exposure the context of cold-protection and gloves (Chen *et al.*, 1994; Shitzer *et al.*, 1998). An evaluation of gloves conducted by Branson *et al.* (1988) in a moderate environment (~26°C) demonstrated that skin temperature, perceived temperature and perceived thermal discomfort all increased similarly during exercise irrespective of the glove material worn. Interestingly, hand blood flow has been observed to limit increases in other areas during heat stress (Hirata *et al.*, 1993), which may contribute to maintaining blood pressure while still improving heat dissipation. Coverage of the hands would negate these benefits and possibly increase thermal load.

### **2.5.5 Clothing Summary**

Clothing may be improved by garment design and fabric development. Factors for consideration are fabric thickness, blockage of radiative heat (and damaging UV rays), loose clothing that allows increased air circulation, clothing coverage, and fibre construction or weave. The design of clothing must favour heat transfer between the skin and the surrounding environment, especially enhancing evaporation at the skin surface, in order to alleviate heat storage and improve performance.



## 2.6 SUMMARY

The discussions contained in this review of literature have concentrated on the physiological and metabolic demands of clothing and environmental conditions with special reference to soccer specific intermittent exercise.

- ✕ Exercise performance is affected by ambient and core temperature. Although little research is available regarding the thermoregulatory responses to intermittent exercise, the data that have been presented suggest that intermittent exercise may exacerbate the effects of elevated ambient temperature. Core temperature during exercise is somewhat dependent upon external temperature within an environmental 'prescriptive zone', above this range, core temperature reaches an 'uncompensable' state where heat loss is insufficient to offset further heat storage and core temperature rises. Choices of clothing have shown that even small changes can alter the microenvironment next to the skin surface and impact upon whole-body physiological, metabolic and thermoregulatory responses. Peripheral clothing alone has been reported to cause significant changes in thermoregulatory responses and thermal comfort. Therefore clothing materials that assist heat dissipation in a warm environment and may improve performance and give an athlete, such as an elite soccer player, the competitive edge.

Soccer match-play induces high physiological demands upon a player compared with continuous exercise of an equivalent average intensity. Physiological demands are further increased in a hot environment and performance is compromised. Preparations for a soccer match should include considerations of clothing and environmental conditions as these factors have considerable ramifications for players' performances.



## CHAPTER 3. THEORETICAL AND METHODOLOGICAL BACKGROUND



### 3. THEORETICAL AND METHODOLOGICAL BACKGROUND

*This chapter contains the methodological procedures used throughout the experimental work and the results of one study relating to the development of a soccer-specific intermittent protocol replicating the activity profile of outfield players.*

#### 3.1 GENERAL METHODOLOGY

Approval by the Human Ethics Committee at Liverpool John Moores University was obtained for all procedures and methodology within this work. The participants were all in good health and regularly took part in exercise (moderate level exercise three times a week). Written and verbal information regarding the nature and risks of the experimental procedures was offered to all participants. All freely volunteered for the study and signed a standard consent form (JMU subject consent form EC3, Appendix 6) and were free to withdraw from the experiments at any time, without prejudice.

##### 3.1.1 Pre-Test Assessments

Maximal oxygen consumption ( $\dot{V}O_{2\max}$ ) was assessed on a motorised treadmill (Chapter 4, Section 4.2, Quinton Instruments, Washington, USA; Chapters 6 and 7, Pulsar, HPCosmos, Nussforf-Traunstein, Germany). Participants performed 5 min of submaximal exercise at  $10 \text{ km h}^{-1}$  as a standard warm-up. The observed heart rate obtained during this period was then used to determine an appropriate starting speed to allow the test to complete between 8 - 12 min. Every 2 min the speed was increased by  $1 \text{ km h}^{-1}$ . If the treadmill speed reached  $18 \text{ km h}^{-1}$ , the elevation was then increased by 2% every 2 min until exhaustion.



Expired air was continuously collected and analysed using either a Sormedics 2900 Metabolic Cart (Yorbalinda, California, USA) for data presented in Chapter 4, Section 4.2 or a Pulmolab EX670 Mass Spectrometer (Morgan Medical, Gillingham, UK) for data presented in Chapter 6. Standard calibration procedures using gases of known concentrations and syringe of known volume, were carried out prior to measurement of respiratory gases. Details of calibration for the two machines are contained in Appendix 2.

Throughout the maximal test, heart rate was measured continuously at 15-s intervals using short-range radio telemetry (Accurex Plus, Polar Electro, Kempele, Finland).

The British Association for Sport and Exercise Sciences' (BASES) guidelines (1997) were followed to ensure that maximal oxygen consumption was reached. Respiratory exchange ratio was required to attain 1.15 or above and increases in  $\dot{V}O_2$  were less than  $2 \text{ ml kg}^{-1} \text{ min}^{-1}$  with a new workload. Participants were also verbally encouraged throughout the final stages of the test to ensure that they reached true exhaustion.

### **3.1.2 Experimental Methodology**

Prior to each of the experimental sessions the subjects were asked to refrain from strenuous exercise during the previous 24 h, consumption of alcohol for 24 h, caffeine for 12 h and food for 3 h. Participants were also advised to drink a minimum 1.5 l of water per day to ensure they were euhydrated. On arrival at the laboratory the participant gave verbal confirmation of these directions. For individual participants each test was scheduled for the same time of day at least three days apart to negate the effects of circadian variation that may be present in the variables measured (Reilly *et al.*, 1984; Reilly and Brooks, 1986; Aoki *et al.*, 1995; Deschenes *et al.*, 1998).



Prior to testing, and upon completion, the subjects weighed themselves nude using precision calibrated weighing scales (Seca, UK), accurate  $\pm 50$  g, for the determination of body weight loss. Respiratory weight losses during typical exercise have been quantified as in the region of  $2 - 5 \text{ g min}^{-1}$  (Mitchell *et al.*, 1972) and will be considered as negligible throughout this work. Following the initial weighing, the participant inserted a rectal temperature probe to a depth of 10 cm beyond the anal sphincter to allow continuous measurement of core temperature ( $T_r$ ). The participant then rested in a seated position at which time the thermistors were placed upon the skin with sterile surgical adhesive tape (Transpore, 3M, Michigan, USA).

The subject was fitted with a short-range radio telemetry system for the measurement of heart rate (Accurex Plus, Polar Electro, Kempele, Finland) in all studies. Measurements were recorded at 15-s intervals during the period of the experiments

Mean skin temperature ( $\bar{T}_{sk}$ ) was assessed according to the methods of Ramanathan (1964) by the placement (Table 3.1) of four specific regional thermistors (Grant thermistors, Grant Instruments, Cambridge, UK) on the chest, forearm, thigh and leg. These data were then used to calculate the weighted mean skin temperature ( $\bar{T}_{sk}$ ):

**Equation 3.1.** Calculation of weighted mean skin temperature.

$$\bar{T}_{sk} (^{\circ}\text{C}) = (0.3 \times \text{chest}) + (0.3 \times \text{arm}) + (0.2 \times \text{thigh}) + (0.2 \times \text{leg})$$

Mean body temperature was also calculated as (Hardy and Dubois, 1938):

**Equation 3.2.** Calculation of weighted mean body temperature.

$$\bar{T}_b (^{\circ}\text{C}) = (0.8 \times T_r) + (0.2 \times \bar{T}_{sk})$$

Where:



$\overline{T}_b$	=	weighted mean body temperature (°C)
$\overline{T}_{sk}$	=	weighted mean skin temperature (°C)
$T_r$	=	rectal temperature

Thermistors and the rectal probe were connected to a data logger (Squirrel meter 1250, Grant Instruments, Cambridge, UK), which recorded temperatures every 60 s. For ease of movement the majority of thermistors were placed on the left hand side of the body to allow the wires from the thermistors to be routed easily to the data logger. Environmental temperature was also monitored throughout the exercise period.

**Table 3.1.** Anatomical placement of all skin temperature thermistors used.

Area	Position
<i>Mean Skin Temperature (<math>\overline{T}_{sk}</math>):</i>	
Chest	mid-point between clavicle and nipple
Arm	lateral aspect of upper arm
thigh	mid-point of anterior thigh
leg (shin)	mid-point of tibialis anterior
<i>Other Areas:</i>	
back	superior aspect of scapula
calf	mid-point of calf
thumb	palmar surface of 1 <sup>st</sup> row phalange
index finger	palmar surface of 1 <sup>st</sup> row phalange
fourth finger	palmar surface of 1 <sup>st</sup> row phalange
hand 1 (palmar)	palmar surface of metacarpus
hand 2 (dorsal)	dorsal surface of metacarpus
wrist 1 (palmar)	palmar surface of carpus
wrist 2 (dorsal)	dorsal surface of carpus
toe	between first and second toes
instep	mid-point of the foot arch
ankle	lateral aspect of lower ankle
dorsal foot	mid-point of dorsal area of foot

During the periods of exercise, participants were requested to give a rating of perceived exertion from one of two Borg Scales for Rating of Perceived Exertion. The Borg scale (Borg, 1970) was designed to have a linear relationship with workload and has a high degree of validity and reliability. The modified category ratio scale shown in Table 3.2



was selected when ease of communication by hand signals was necessary, in particular when a subject was required to wear a mouthpiece for gas analysis making verbal communication difficult.

**Table 3.2.** Modified Borg (1982) 12-point scale of perceived exertion.

Rating	Description
0.5	very, very light
1	Very light
2	light
3	moderate
4	somewhat hard
5	
6	Hard
7	
8	very hard
9	
10	very, very hard
•	Maximal

When communication by way of hand signals was not necessary participants were asked to rate perceived exertion using the original Borg Scale (Table 3.3). Borg (1982) has suggested the original scale as the scale of preference for the majority of occasions during exercise testing.



**Table 3.3.** Original Borg (1970) 15-point scale of perceived exertion.

Rating	Description
6	
7	very, very light
8	
9	very light
10	
11	Light
12	
13	somewhat hard
14	
15	Hard
16	
17	very hard
18	
19	very, very hard
20	Maximal

### 3.1.3 Thermal Balance

Heat storage ( $\pm S$ ) was calculated from the equation of Burton (1935) and is expressed in units of  $\text{W m}^{-2}$ .

**Equation 3.3.** Calculation of heat storage.

$$\pm S = \Delta \bar{T}_b \cdot mass \cdot ctissues \cdot A_D^{-1}$$

Where:

- $S$  = heat storage ( $\text{W m}^{-2}$ )
- $\Delta \bar{T}_b$  = change in overall mean body temperature,  $\bar{T}_b$ , (Equation 3.2) during the exercise period ( $^{\circ}\text{C}$ )
- $ctissues$  = average specific heat of the body tissues ( $1.29 \text{ W kg}^{-1} ^{\circ}\text{C}^{-1}$ )
- $A_D$  = body surface area (Dubois and Dubois, 1916) ( $\text{m}^2$ ).



Body surface area may be calculated using the following formula:

**Equation 3.4.** Calculation of body surface area (Dubois and Dubois, 1916).

$$A_D = 0.202 \times W^{0.425} \times H^{0.725}$$

Where:

- $A_D$  = Body surface area (Dubois and Dubois, 1916) (m<sup>2</sup>)  
 $W$  = Weight of body (kg)  
 $H$  = Height of body (m)

The determination of body heat storage using the above formulae has been found to be a reliable estimation, comparable to the measurement of heat storage by calorimetry (Aoyagi *et al.*, 1995) and is valid in all conditions except when heavily clothed, such as when wearing protective clothing.

### 3.2 BLOOD ANALYSES

Health and Safety procedures for handling human body fluids and sharps policies were strictly adhered to when drawing blood samples.

Venous blood samples were drawn immediately pre-exercise and immediately post-exercise for analysis in the experimental work detailed in Chapters 6 and 7. The use of a tourniquet was not possible due to the measurement of prolactin, a stress hormone. Prior to the pre-exercise sample the subjects were requested to rest in a supine position for approximately 20 min. Following the period of rest, a 10 ml sample of venous blood was taken from the median cubital vein in the forearm.

Arterialised capillary blood was drawn pre-exercise, mid-exercise, immediate post-exercise and 5 min post-exercise using the method of finger-prick sampling for the



analysis detailed in Chapters 4 and 5. In Chapters 6 and 7, finger prick samples were additionally taken mid-exercise (22-23 min) and at 5 min post-exercise.

Various measurements and analyses from the venous samples were taken. Plasma osmolality, haematocrit, haemoglobin, lactate, glucose, non-esterified fatty acids and prolactin were analysed pre-exercise and post-exercise with lactate being measured additionally from mid-exercise and 5 min post-exercise finger prick samples. Full methodology is included in Appendix 3 (page 284).

### **3.3 *STATISTICAL METHODS AND PRESENTATION***

Statistical definitions, symbols and notations confirm to guidelines set out by the Council of Biology Editors (1994) and utilised by the Journal of Sports Sciences. The units used conform to the *Système International d'Unités* (SI Units).

All data are presented as mean ( $\bar{x}$ )  $\pm$  standard deviation ( $s$ ). Standard error ( $s_{\bar{x}}$ ) about the mean is often quoted in literature; however, this method can be misleading in giving the impression that greater accuracy has been attained (Altman, 1982).

When more than one measurement was taken from each subject under different experimental treatments, the method of repeated measures analysis of variance was used by means of the statistical software package SPSS. This method is used when the same dependent variable is measured from an individual more than once. The ANOVA results were corrected by the Huynh-Feldt Epsilon ( $\epsilon$ ) adjusted degrees of significance where the sphericity is violated due to unequal variance and covariance. Sphericity is an assumption that data are homogenous having equal variance and the Huynh-Feldt  $\epsilon$  corrected result reduces the possibility of a Type I error (a significant result due to chance) and is the most



conservative of correction factors. The resulting ANOVA is more valid (Thomas and Nelson, 1996). Results of ANOVA analysis are presented in the following format: e.g.  $F_{1,5} = 15.876, P = 0.010$ . When the results are corrected using Huynh-Feldt  $\epsilon$  the degrees of freedom are adjusted and degrees of freedom are quoted with decimal places.

The Student t-test was also used to define differences when a variable was only measured once (i.e. analysis of parameters such as heart rate in Section 4.3, page 137). Analysis of the results was carried out with two methods. Certain variables were examined using analysis of serial measurements (Mathews *et al.*, 1990) where the change from baseline to end-of-test was analysed using a t-test (i.e. foot skin temperature analysis in Section 4.1, page 106).

Tukey's "Honestly Significant Difference" (HSD) post-hoc test for multiple comparisons was carried out where significant differences were found within a general linear model repeated measures ANOVA (Vincent, 1999). The Tukey's HSD test is used to determine precisely where differences in the data lie. A detailed explanation of the Tukey's HSD post-hoc test is contained in Appendix 5 (page 295).

Significance was accepted at the alpha 0.05 level to protect against Type I errors.  $P$  values are reported as exact values.

When significance was not attained the values of Eta ( $R^2$ ) and observed power were examined to determine if any worthwhile effects were present. The term Eta represents the ratio of the variance due to the treatment and the total variance, and estimates the size of effect (Vincent, 1999). Values for Eta can range between 0 and 1 and are usually reported as a percentage. That is, if Eta = 0.65 then 65% of the variance can be explained by the treatment effects and 35% is unexplained. The greater the value of Eta, the more



worthwhile the treatment effect. The calculation of power is the ability to reject a null hypothesis (Vincent, 1999). If significance has not been attained and power is low, a type II error cannot be ruled out. A type I error rate (Alpha) is the probability of being wrong when you say, “There is a significant effect” with acceptable probability < 5% and a type II error rate (Beta) is the probability of being wrong when you say, “There is no significant effect” with acceptable probability <10-20%.

Occasional missing values were estimated relative to values in the adjacent row and column as suggested by Winer et al. (1991):

**Equation 3.5.** Replacement of missing values (Winer *et al.*, 1991).

$$x = \text{row mean} + \text{column mean} - \text{grand mean}$$

Winer et al. (1991) themselves observed that this method was not ideal. Nonetheless, when an occasional observation is missing it is useful in allowing further analysis where missing data would prevent it.

The number of decimal places used is reported throughout commensurate with the precision of the method of measurement.

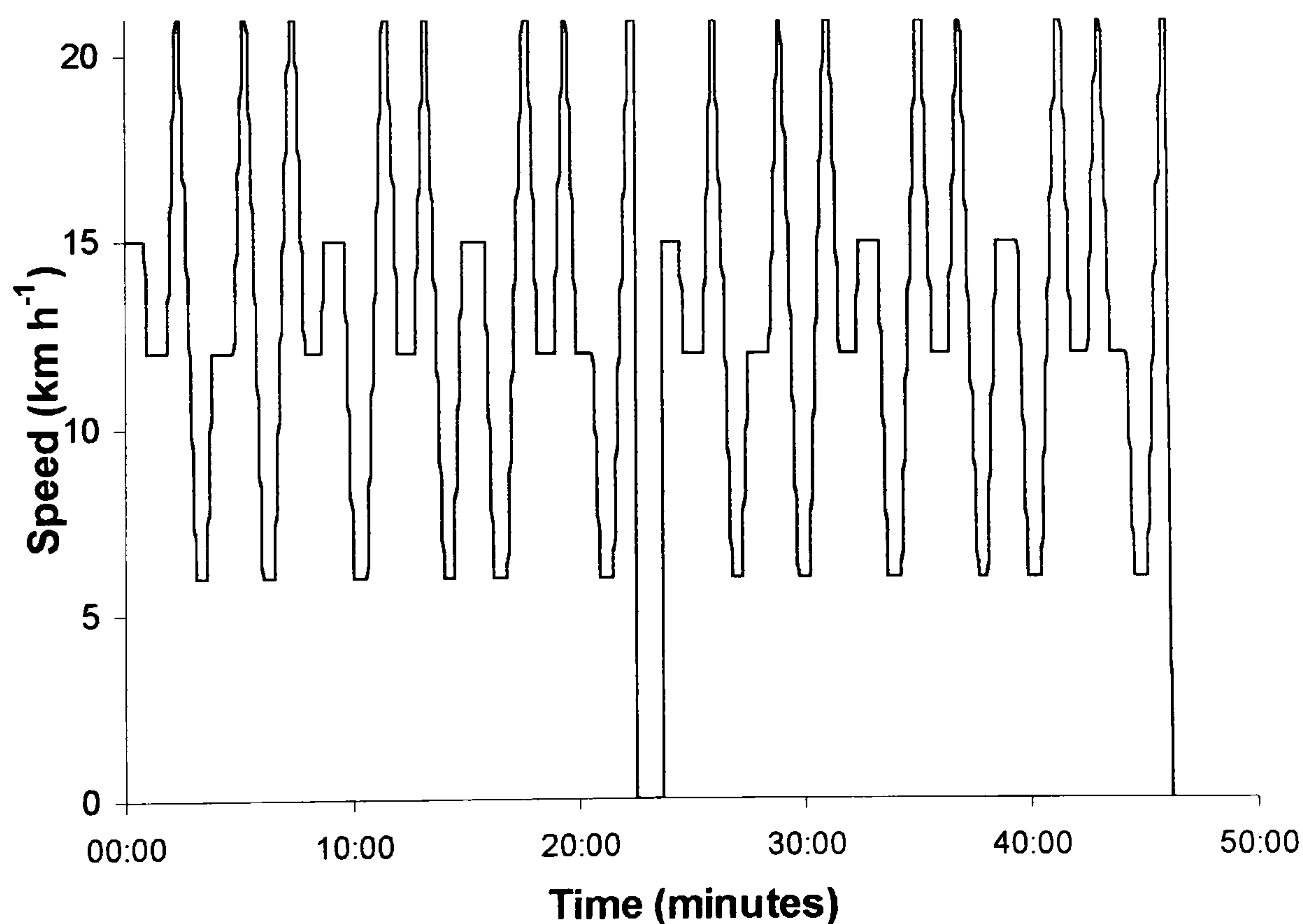
### **3.4 EXERCISE PROTOCOLS**

The use of soccer specific intermittent exercise protocols was necessary to replicate the activity profile and physiological demands of soccer players under laboratory conditions on a treadmill. Three exercise protocols are utilised within this research and are described in detail below.



### 3.4.1 Outfielder Specific Protocol

The experimental work detailed in sections 4.1, 4.2 and 4.2 utilised a soccer specific intermittent protocol designed by Drust (1997). The protocol was designed using data from Reilly and Thomas (1976) and was structured as two halves of 22 min 30 s separated by a 70-s static pause giving a total time of 46 min 10 s. The extra time of 1 min 10 s was considered to represent added stoppage time. The replication of two halves of activity allowed for comparisons between first and second periods of the protocol. Figure 3.1 shows the changes in treadmill speed in real-time taking into consideration the average time taken to change between speeds.



**Figure 3.1.** Real time representation of the changes in treadmill speed during the soccer-specific protocol run twice over a total of 46 min 10 s.

The treadmill used was manufactured by Quinton Instruments, Washington, USA and the use of the protocol on this machine was determined as reliable and repeatable with a reported (Drust, 1997) coefficient of variation of 4.8% and limits of agreement of 9.4%.



These values show the low amount of variation of the protocol and are within the range of 10-15% suggested by Stokes (1985) as acceptable. A maximum variation of 3.6 s was deemed as an acceptable variation in time to change between activity bouts (Drust, 1997).

Prior to starting the exercise protocol, each participant completed a standardised warm-up for 5 min at 10 km h<sup>-1</sup> followed by 2 min of passive stretching focused on the lower body.

### **3.4.2 Goalkeeper Specific Protocol**

The physiological demands of goalkeeping are lower than that of outfield players (Reilly and Thomas, 1976). A goalkeeper travels approximately 4 km during a 90-min game of soccer compared to approximately 10 km for an outfield player. Therefore a specific intermittent protocol was necessary to replicate the activity profile. A goalkeeper-specific intermittent protocol was formulated using data published by Reilly and Thomas (1976), which are the only available data on motion analysis of goalkeepers. The back-pass rule of 1992 has prevented a goalkeeper from picking up the ball when a player from the same team passes back and hence this ruling may have altered the activity profile slightly.

The activity was conducted on a non-motorised treadmill (Woodway, Seattle, USA) to allow for instantaneous changes in speed without long delays necessary when changing speeds on the available motorised treadmill used in Drust's (1997) outfielder protocol described above. The protocol (Figure 3.2) utilised four self-paced actions:- walk, jog, cruise, and sprint. Participants attempted to maintain speeds of 5 km h<sup>-1</sup> during walking, 9 km h<sup>-1</sup> during jogging, 12 km h<sup>-1</sup> during cruising and maximal effort for sprinting. The speeds utilised may seem low; however, a non-motorised treadmill requires effort to move the belt and maintain momentum and the extra force required must be taken into consideration.



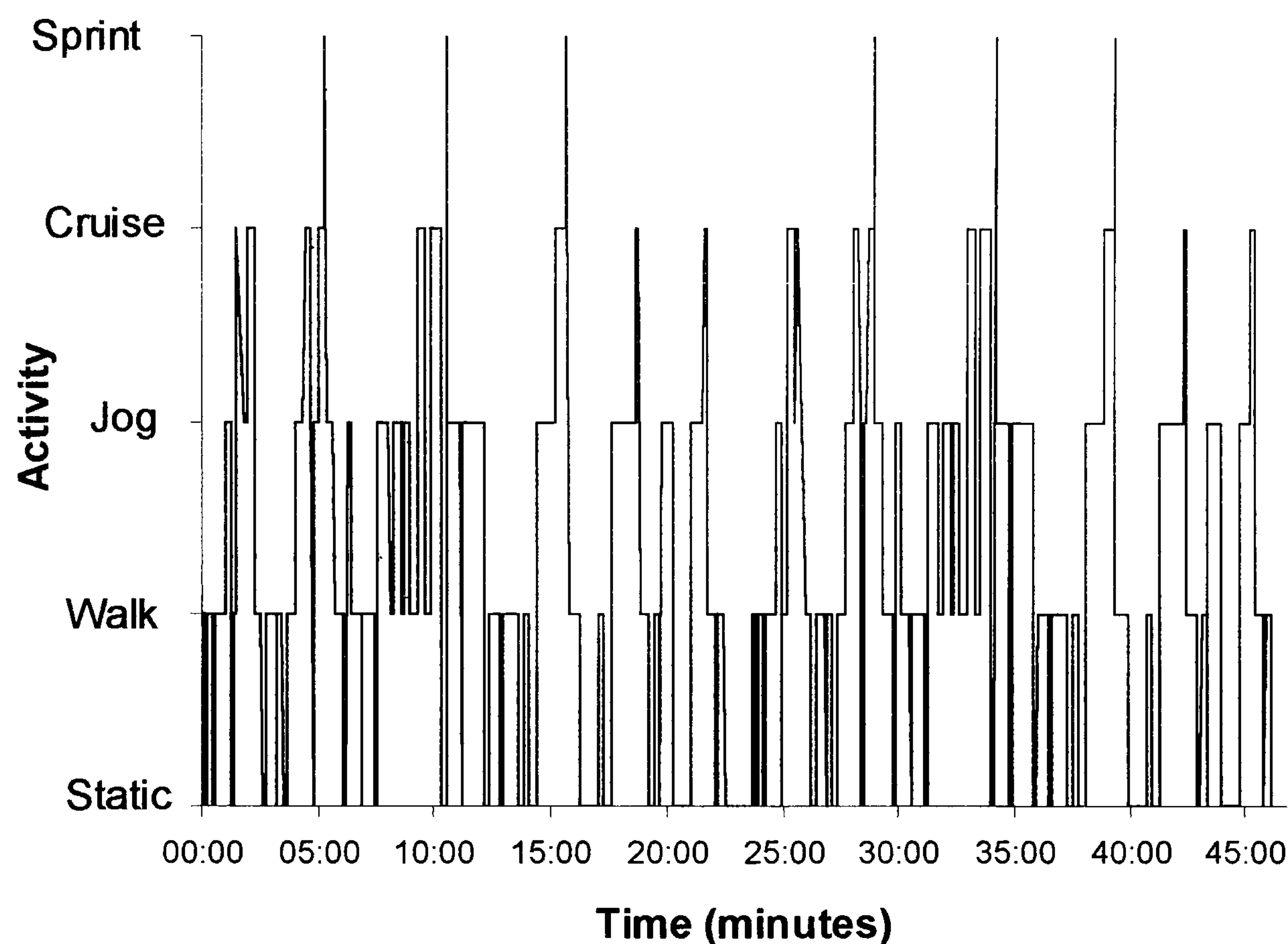
To ensure accuracy between trials, information about the protocol was imparted to each participant via verbal instructions recorded on an audiocassette played during each experimental session. Timings from the cassette were cross-referenced with a printed sheet of the protocol timings during each experimental session to ensure that possible stretching of the tape would not alter the activity profile. No differences in timings were observed. This protocol was utilised in the experimental work detailed in section 4.3.

The repeatability of the protocol was also calculated as large variations between tests will invalidate the test. The use of correlation coefficients, although commonly reported when assessing repeatability, is not recommended, as they measure relationship and not agreement between two data sets. The method of limits of agreement is a more suitable method of assessing agreement between measurements (Bland and Altman, 1986; Atkinson, 1995; Drust *et al.*, 1997; Atkinson and Nevill, 1998).

The repeatability of the treadmill goalkeeper protocol was ascertained by measuring mean heart rate of 10 subjects completing two separate tests, unfortunately the total distance travelled could not be measured as the treadmill counter was not functional.. A one-way analysis of variance (ANOVA) was used to establish if there were any differences in heart rate between trials. No significant bias ( $P = 0.54$ ) was observed between the two tests. The data were then analysed for measurement error and variance between trials using coefficient of variation and limits of agreement (Bland and Altman 1986). The overall mean heart rate was  $137 \pm 10$ , coefficient of variation 7.6%, and limits of agreement  $5.75 \text{ beats min}^{-1}$ , that is, 95% of mean heart rate values will lie within approximately  $6 \text{ beats min}^{-1}$  of one another. The extremely low coefficient of variation and limits of agreement indicated the low amount of variability of heart rate between repeats of the protocol and therefore, given the technical limitations of the laboratory setting, the



protocol was considered reliable and valid for use as a soccer goalkeeper match-play-simulation.



**Figure 3.2.** Diagrammatic representation of the 46 min 10 s goalkeeper-specific intermittent protocol.

### **3.5 PRODUCTION OF A NEW OUTFIELDER-SPECIFIC SOCCER PROTOCOL**

#### **3.5.1 Introduction**

The physiological demands of soccer are characterised by the variable intensities of low to moderate activities such as walking, jogging and running superimposed with high activity exercise such as cruising and maximal sprinting (Reilly, 1994; Bangsbo, 1994b). The work-rate profile of a soccer player has been determined by observing actual match-play and carrying out motion analysis of the time spent performing each activity or the



distance covered by each activity. The resultant work-rate profile of a soccer player may then be utilised to recreate match-play in a laboratory setting.

Several researchers have examined physiological responses to non-specific intermittent exercise in the form of work-rest patterns and shuttle running (Nicholas *et al.*, 2000). These studies provide an assessment of physiological performance to soccer type activities rather than a study of physiological responses to soccer match-play conditions.

The soccer specific treadmill protocol of Drust (1997) was initially used; however, this was found to be too intensive for university league players and evoked elevated blood lactate, RPE and heart rates compared to previously reported values. A more accurate laboratory-based protocol, which more closely duplicates soccer match-play, was necessary to allow the imitation of physiological demands during match-play. Additionally, the treadmill for which Drust's (1997) protocol was designed was no longer available for use.

The aim of this study was to devise an intermittent protocol for a programmable motorised treadmill (Pulsar, HP Cosmos, Nussforf-Traunstein, Germany) that simulates soccer match-play work-rates and activity profiles as closely as practically possible in a laboratory setting. The new protocol was used to compare the effects of different clothing assemblies (Chapter 5), environmental conditions (Chapter 6) and a combination of clothing and environment (Chapter 7) on the physiological responses during soccer-specific intermittent exercise.

### **3.5.2 Methods**

The devised soccer-specific intermittent protocol consists of the five different exercise intensities that are displayed in soccer match-play:- standing, walking, jogging, cruising



and sprinting. The percentage of the total time spent in each activity was calculated using several different research publications describing time-motion analysis (Van Gool *et al.*, 1988; Yamanaka *et al.*, 1988; Bangsbo *et al.*, 1991; Bangsbo, 1994b; Drust *et al.*, 1998a; Drust *et al.*, 1998b). It was necessary to re-categorise some activities into the five groups listed to allow comparison of actions categorised slightly differently by authors. The calculated percentages are shown in Table 3.4.

Backwards, sideways and actions in contact with the ball cannot be included because of the technical impracticalities when using a motorised treadmill. These actions were included in the next most suitable category, i.e. backwards jogging was categorised as jogging.

**Table 3.4.** Time spent (% of total) in each physical activity during soccer match-play.

	Bangsbo (1994)	Reilly & Thomas (1976)	Bangsbo et al. (1991)	Drust et al. (1988)	Yamanaka et al. (1988)	Calculated Mean
Standing	17	0	17	11	5	10.0
Walking	40	28	40	32	50	38.0
Jogging	35	40	35	42	35	37.4
Cruising	5	21	5	11	7	9.8
Sprinting	3	11	3	4	3	4.8
	TOTAL					100 %

Treadmill speeds were calculated using several sets of data listed in Table 3.5. The data analysed here were obtained from professional standard soccer players. However, soccer players of lower division standard were found to run at more moderate speeds compared to elite players (Bangsbo, 1994b). As the treadmill protocol is to be used primarily on University League and recreational players, the differences in utilisation of their physical capacity will be taken into consideration.



**Table 3.5.** Summary of speeds ( $\text{km h}^{-1}$ ) of activities used.

	Bangsbo (1994)	Bangsbo et al. (1991)	Van Gool et al. (1988)	Drust (1997)	Calculated Mean	Speeds Used
Walking	6.0	6.0	6.0	6.0	6.0	6
Jogging	12.0	10.0	12.5	12.0	11.6	12
Cruising	15.0	16.5	21.3	15.0	17.0	15
Sprinting	30.0	30.0	27.1	21.0	27.0	21

Special notice of work previously carried out on a soccer specific protocol (Drust, 1997) was also taken. Subjects who undertook pilot testing by Drust found high intensity cruising and sprinting too strenuous at the speeds suggested by the motion analysis of Van Gool *et al.* (1988). The speeds finally chosen for each activity in this protocol were identical to the final speeds chosen in Drust's protocol: walking  $6 \text{ km h}^{-1}$ , jogging  $12 \text{ km h}^{-1}$ , cruising  $15 \text{ km h}^{-1}$  and sprinting  $21 \text{ km h}^{-1}$ .

#### 3.5.2.1 Reliability and Repeatability

Measurement repeatability was extremely important to ensure the treadmill protocol would produce accurate and consistent soccer tests on each occasion of use. Large variations in a test method or measurement will render the recording of a test variable invalid. The use of correlation coefficients, although common in research, is not recommended, as they measure relationship and not agreement between two data sets. The method of limits of agreement is suggested as a more suitable method of assessing agreement between measurements (Bland and Altman, 1986; Atkinson, 1995; Drust *et al.*, 1997; Atkinson and Nevill, 1998).

The repeatability for the time taken for the treadmill to alter speed between activity sections was analysed throughout the protocol. This was ascertained by timing each speed alteration during two sessions of 10 measurements using a stopwatch with the



treadmill unloaded. A one-way analysis of variance (ANOVA) was used to establish if there were any differences between trials. The total distance travelled over the 45 minutes was also measured over two sessions of 10 measurements using the distance meter on the treadmill control and display panel. The data were then analysed for measurement error and variance between trials using coefficient of variation and limits of agreement (Bland and Altman 1986).

### 3.5.2.2 *Validity*

The validity with which the treadmill protocol represents soccer type activity was also assessed. Physiological measurements of heart rate, RPE,  $\dot{V}_E$ , relative  $\dot{V}O_2$  ( $\text{ml min}^{-1} \text{ kg}^{-1}$ ) and  $\% \dot{V}O_{2 \text{ MAX}}$  were recorded from a group of 20 subjects<sup>1</sup> to allow comparisons with data obtained from real match-play conditions and establish how closely the protocol simulates the physiological demands of soccer.

Prior to starting the exercise protocol, each participant completed a standardised 5-min warm-up at  $10 \text{ km h}^{-1}$  followed by 2 min of passive stretching focused on the lower body.

### 3.5.3 Results

The protocol was composed of two 22-min blocks separated by a 1-min static pause run concurrently to give a total test time of 45 minutes. The halfway pause was necessary to allow the restarting of the treadmill programme and also gave an opportunity to take a mid-test measurement such as a blood sample. Each half comprised 3 static pauses (1 of 60 s, 1 of 30 s and 1 of 15 s), 20 sections of walking (1 of 33 s, 1 of 30 s, 18 of 25 s), 15 jogging bouts (5 of 49 s, 10 of 36 s), 11 bouts of cruising (11 of 12 s) and 8 sprints (1 at

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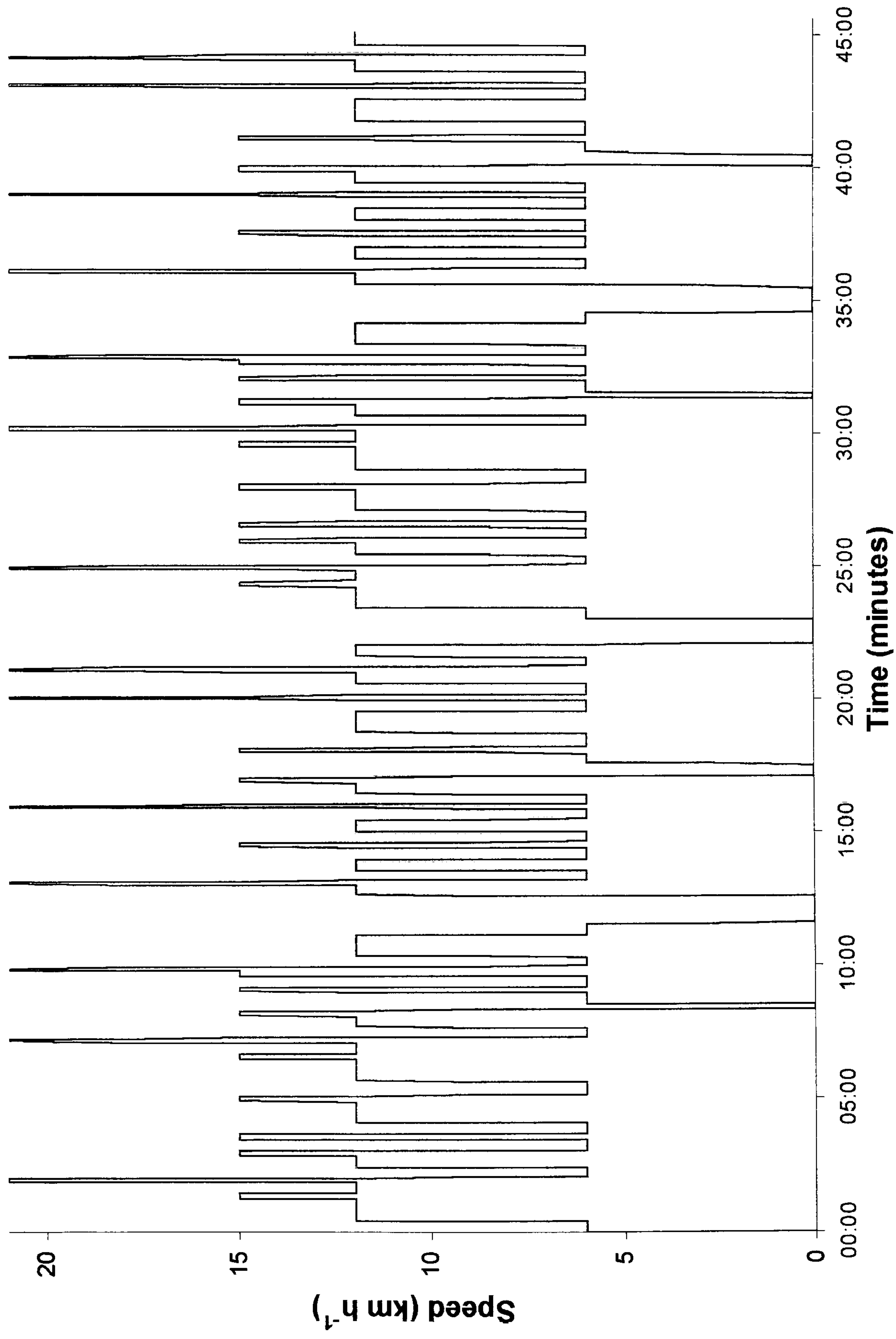
<sup>1</sup> Due to technical problems with the gas analysis system only 5 subjects had reliable measurements of ventilation and only 2 subjects had reliable measurements of oxygen consumption.



9 s, 7 at 8 s). The sequences of these activities are illustrated in Figure 3.3 shown as the entire 45-minute protocol. The protocol's profile is a direct translation of the speeds of the treadmill and the average time taken to change between each activity.

For a full listing of the speed changes please refer to Appendix 4 on page 291. For users of a Pulsar treadmill, instructions for inputting the program steps may be found on page 292.





**Figure 3.3.** Real-time representation of the changes in treadmill speed during the new soccer-specific protocol run twice for a total 45 min.



### 3.5.3.1 Reliability and Repeatability

The time taken to change between each speed setting was measured over two tests of 10 trials for each speed change using a stopwatch and unloaded treadmill. A one-way ANOVA was used to determine if there were any large systematic bias between test and re-test. No significant bias ( $P > 0.05$ ) was observed between the samples. Further analysis was carried out using coefficient of variation and limits of agreement (Bland and Altman, 1986). Table 3.6 summarises the results of the analysis and shows the mean ( $\pm s$ ) time taken, coefficient of variation and limits of agreement for all of the possible changes in activity. The limits of agreement for the changes in treadmill speed range between 0.07 and 0.37 s. That is, 95% of changes between speed bouts will be accurate to within 0.37 s or less.

**Table 3.6.** Time taken for the treadmill to change between activity sections.

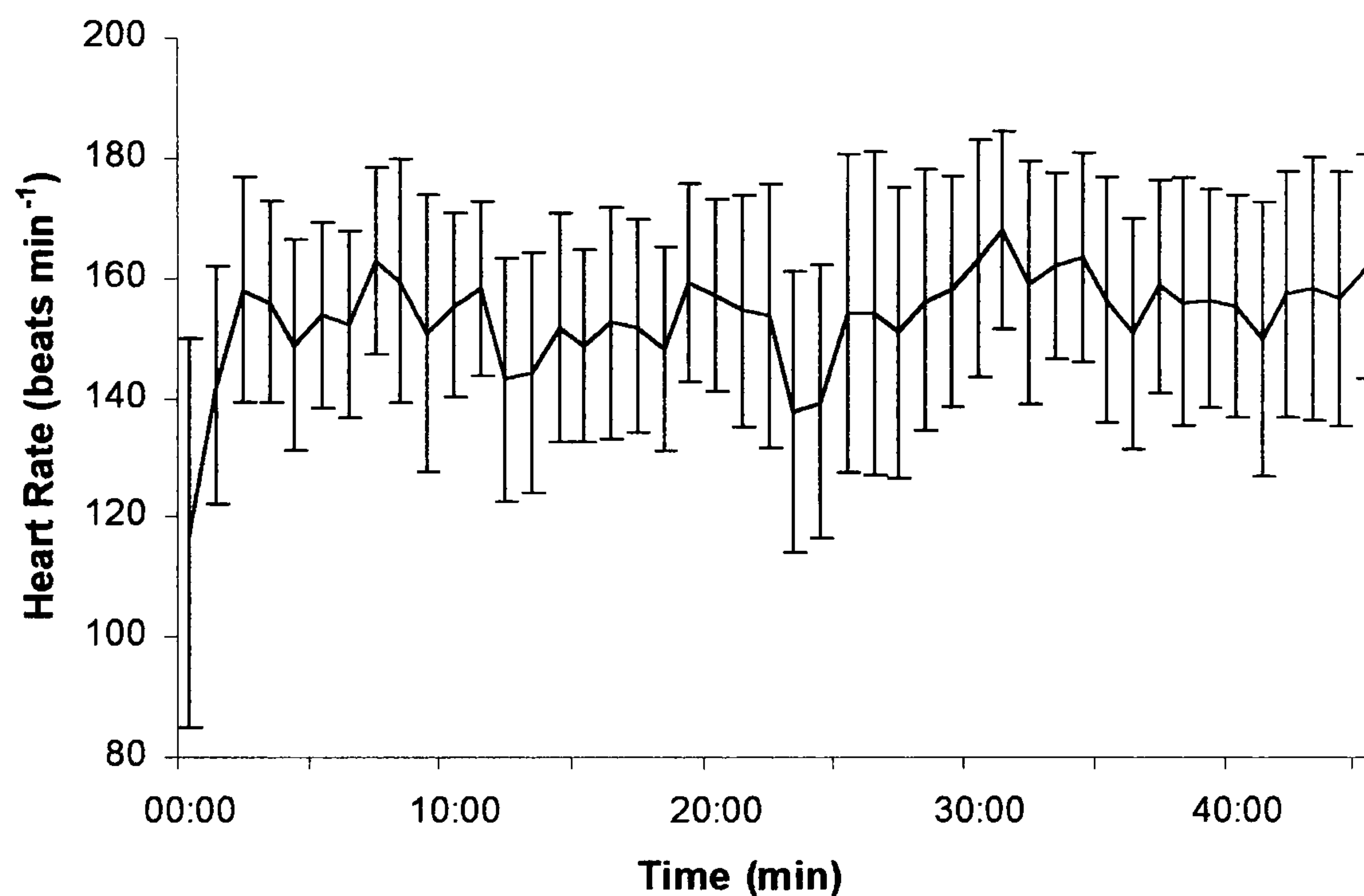
Speed Change (km h <sup>-1</sup> )	Mean $\pm s$ (s)	Coefficient of Variation (%)	95% Limits of Agreement (s)
0 to 6	2.3 $\pm$ 0.1	7.3	0.33
0 to 12	4.5 $\pm$ 0.1	4.3	0.37
6 to 0	1.8 $\pm$ 0.1	4.3	0.15
6 to 12	2.3 $\pm$ 0.1	5.2	0.23
6 to 15	3.4 $\pm$ 0.1	4.2	0.28
6 to 21	5.5 $\pm$ 0.1	2.0	0.22
12 to 0	3.4 $\pm$ 0.2	4.3	0.29
12 to 6	2.4 $\pm$ 0.1	4.8	0.08
12 to 15	1.3 $\pm$ 0.1	6.4	0.17
12 to 21	3.4 $\pm$ 0.0	1.0	0.07
15 to 0	5.0 $\pm$ 0.1	2.9	0.29
15 to 6	3.4 $\pm$ 0.1	4.8	0.32
15 to 12	1.4 $\pm$ 0.1	8.9	0.24
15 to 21	2.3 $\pm$ 0.1	7.8	0.36
21 to 6	5.3 $\pm$ 0.2	2.5	0.26
21 to 12	3.4 $\pm$ 0.1	3.0	0.20
21 to 15	2.3 $\pm$ 0.1	3.7	0.17

The overall average of the distance travelled over 22 min of the programmed protocol was  $3.510 \pm 0.002$  km. Therefore, when the full 45-min protocol is run ( $2 \times 22$ -min blocks



separated by a 1-min gap) a total of 7.02 km will be run which then translates into 14.04 km when a 90-min soccer game is simulated. Limits of agreement were calculated for distance covered over the duration of the protocol (22 min) and was calculated at 0.004 km, relating to 95% of programme runs being within 0.004 km of one another.

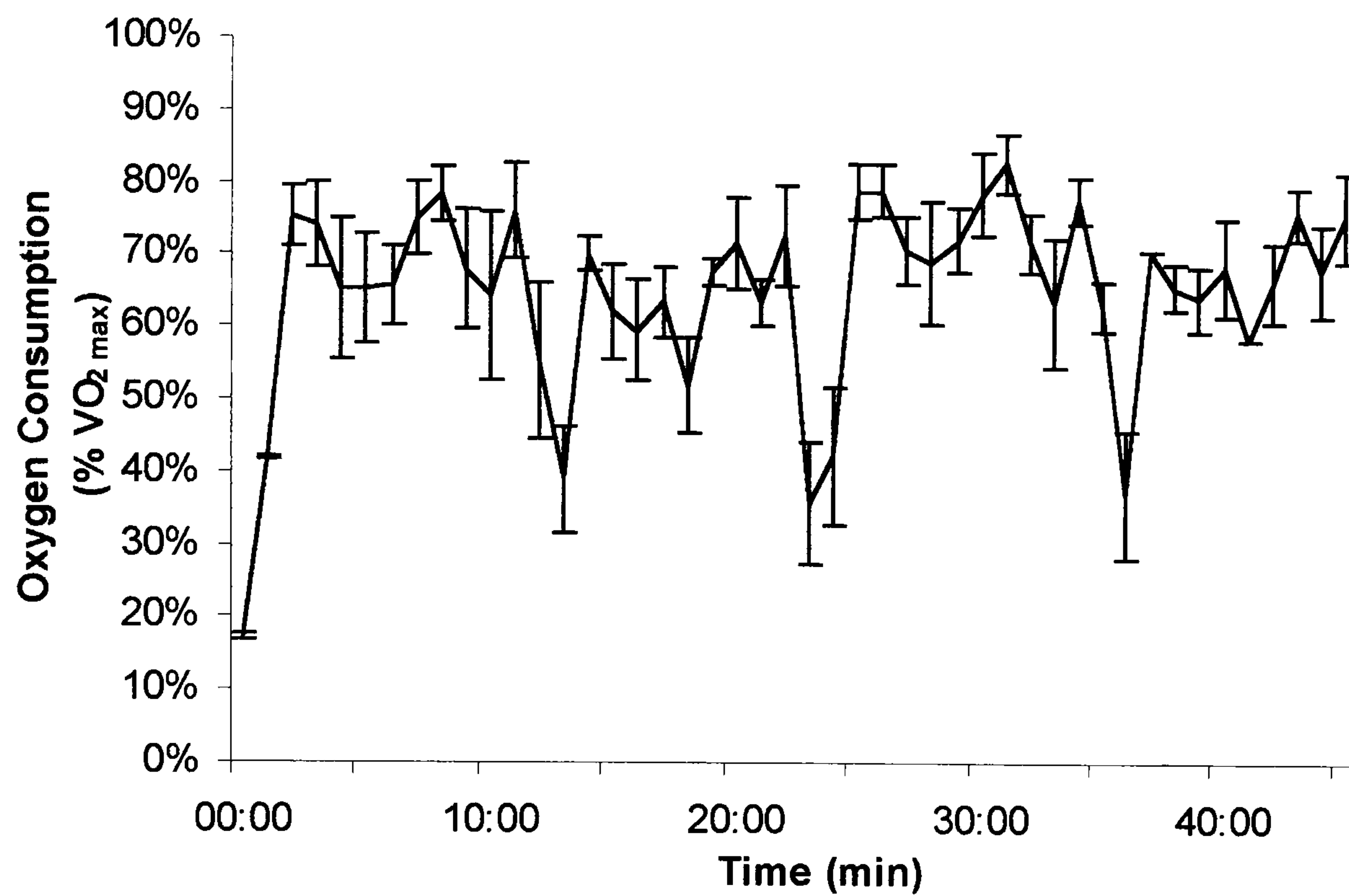
### 3.5.3.2 Validity



**Figure 3.4.** Heart rate response to new soccer specific intermittent protocol ( $n = 20$ ).

Figure 3.4 shows mean heart recorded at 60-s intervals and illustrates the intermittent intensity of the exercise protocol. Heart rates increased over the duration of exercise with the first period of the protocol eliciting an overall mean heart rate of  $151 \pm 21$  beats  $\text{min}^{-1}$  compared to a significantly higher ( $F_{1,19} = 13.01$ ,  $P = 0.002$ ) measurement of  $156 \pm 22$  beats  $\text{min}^{-1}$  during the second period.





**Figure 3.5.** Oxygen consumption response to new soccer specific intermittent protocol ( $n = 2$ ).

As shown for heart rate, oxygen consumption ( $n = 2$ ) displayed in Figure 3.5 also illustrates the intermittent nature of the soccer protocol. The differences between the first period of exercise and the second period of exercise were not significant ( $F_{1,1} = 44.44$ ,  $P = 0.095$ ). A significant effect of time was found for RPE ( $F_{8,152} = 28.34$ ,  $P = 0.0001$ ).

Mean measurements for the whole of the exercise period are displayed in Table 3.7.

**Table 3.7.** Overall physiological responses to soccer specific protocol.

	$V_E$ ( $l\ min^{-1}$ )	$\dot{V}O_2$ ( $ml\ kg^{-1}\ min^{-1}$ )	% $\dot{V}O_{2\ MAX}$	Heart Rate ( $beats\ min^{-1}$ )	RPE
	$n = 5$	$n = 2$	$n = 2$	$n = 20$	$n = 20$
MEAN	64.2	3.2	64.6	154	4
<i>s</i>	13.3	0.7	14.1	21	1



### 3.5.4 Discussion

The repeatability for the treadmill to change between each speed setting and the distance covered during the performance of the protocol program were assessed. The repeatability of these parameters is important as differences in changes in speed would alter the timing of the protocol and affect the physiological demands upon a subject carrying out the protocol. Analysis of changes in treadmill speed was chosen to determine the reliability and repeatability of the equipment used and was determined using limits of agreement and the coefficient of variation, 1.0 – 8.9% and 0.07 – 0.37 s, respectively. The low variation of time taken to change between activities is unlikely to alter the physiological responses of subjects. In fact, it is thought the actual time to change may be even more accurate than the analysis suggests as the method of measurement was via a hand operated stopwatch and human reaction time to the treadmill reaching a given speed may not have been sufficiently fast. The even lower variation in the distance covered over the duration of a programme also suggests that accuracy of time to change speed may be greater than reported as distance was measured using the on-board treadmill display.

A time period of exactly 45 min was chosen, as time motion analysis does not appear to consider the motion characteristics of extra-time separately. A period of 45 min reflects the activity profile of one half of a 90-minute match. The 45-min protocol may be repeated once with a 15-min standard break between two sections to allow the running of an entire soccer match simulation within the laboratory.

During real match-play the intensity of activity can alter at any time and up to 1000 changes have been recorded throughout 90 min with each bout having a mean duration of approximately 5.5 s (Reilly and Thomas, 1976). Such a short duration of activity and high number of changes is not technically possible on the available treadmill. The



programme settings allow for a maximum of 80 changes in activity. A protocol of 45 minutes on the treadmill would incorporate 240 changes in activity compared to the estimated 1000 during real match-play. Although obviously having much fewer changes in speed the protocol does serve to simulate soccer activity much more accurately than intermittent tests more commonly reported in the literature (Ekblom, 1989; Bangsbo and Lindquist, 1992; Odetoyinbo and Ramsbottom, 1995; Nicholas *et al.*, 2000) which contain fewer changes in speed and are often shorter in duration.

The overall mean of 64.6%  $\dot{V}O_{2\max}$  is slightly lower than the values of 70 - 75%  $\dot{V}O_{2\max}$  reported (Reilly, 1996c) for match-play using the relationship between heart rate and  $\dot{V}O_2$  as a method of estimation (Bangsbo, 1994a; Bangsbo, 1994b). However, this latter technique may lead to an overestimation in predicting  $\dot{V}O_2$  by as much as 18% (Hiilloskorpi *et al.*, 1999) and a 15% overestimation during soccer match-play has also been suggested (Rodriguez and Iglesias, 1998a; Rodriguez and Iglesias, 1998b). Estimation of  $\dot{V}O_2$  during actual match-play using heart rate does not take into account psychological reactions and motivational factors, which may raise heart rate without raising oxygen consumption (Rodahl, 1989). Future work with detailed motion analysis and heart rate telemetry of a player during match-play followed by the exact replication upon a more advanced treadmill may serve to address this issue. It should also be noted that the only two subjects whose  $\dot{V}O_2$  data were available for the assessment of validity were extremely physically active and their  $\dot{V}O_{2\max}$  measurements were at the top end of the range reported for elite soccer players with relative values of 70.05 and 69.81 ml kg<sup>-1</sup> min<sup>-1</sup>. It is possible that soccer players of average standard may have found the intensity of the activity to be closer to the range of 70 to 75% of their maximum  $\dot{V}O_2$ . It should also be noted that interaction with the ball has been shown to increase



physiological demands (Reilly and Ball, 1984) while the energy requirements of running backwards and sideways are higher than running forwards (Reilly and Bowen, 1984) and these actions were not possible during the protocol due to technical limitations and safety issues with the treadmill. This may account for the slightly lower heart rates when running on a treadmill compared to actual match-play in the field.

The mean heart rate of  $154 \pm 21$  beats  $\text{min}^{-1}$  shows the overall moderate intensity of the activity. Rodriguez and Inglesias (1998a) and Reilly (1986) found results comparable to this for professional players ( $156 \pm 5$  beats  $\text{min}^{-1}$  and  $157 \pm 5$  beats  $\text{min}^{-1}$  respectively). Rodriguez and Inglesias (1998a) also quoted a mean heart rate of  $148 \pm 19$  beats  $\text{min}^{-1}$  for amateur players during match-play. However, other authors have shown higher heart rate recordings from match-play conditions of up to 171 beats  $\text{min}^{-1}$  (Ali and Farrally, 1991) with typical values of 165 beats  $\cdot \text{min}^{-1}$ . Differences are also evident (Van Gool *et al.*, 1988) between playing positions (Van Gool *et al.*, 1983) and playing systems (Reilly, 1994).

Outfield players can cover between 8 and 12 km over the duration of a 90 min game (Bangsbo, 1994b; Ekblom, 1986) compared to 14.04 km over the duration of 90 min of this protocol. Although this latter figure is above the maximum reported distance covered during a soccer match, the mode of exercise on the treadmill does not incorporate the game-specific manoeuvres, which would add to energy expenditure but reduce the distance covered. The physiological data support an accurate simulation of soccer match-play and therefore the extra distance is not considered excessive.



### **3.5.5 Conclusion**

Given the technical limitations of the laboratory setting, the protocol was considered reliable and valid for use as a soccer match-play-simulation.



## CHAPTER 4. EFFECTS OF CLOTHING AND EQUIPMENT ON PERIPHERAL THERMOREGULATION



## **4. EFFECTS OF CLOTHING AND EQUIPMENT ON PERIPHERAL THERMOREGULATION**

*The following three studies are concerned with the thermoregulation of peripheral areas of the body, in particular the responses to different clothing and equipment localised at the areas of the hands and feet. The first study attempts to quantify the effects of soccer activity on foot skin temperature compared to steady-state activity at the same overall work-rate while the second study examines the effects of different soccer footwear on localised and whole-body thermal responses. The final study in this chapter evaluates the efficacy of phase control materials used in goalkeepers' gloves, during simulated goalkeeping activity.*

### **4.1 EFFECTS OF EXERCISE MODE ON FOOT SKIN TEMPERATURE**

#### **4.1.1 Introduction**

Evaporation of sweat from the skin surface is the major mechanism for the dissipation of heat. Blood is distributed to the skin by dilation of peripheral blood vessels; sweat is then secreted onto the surface of the skin where heat is removed by vascular transfer in turn vaporising sweat. There are many regional differences in skin blood flow and sweating characteristics of the skin (Day, 1967) with the foot reported to have a very high density of sweat glands (Sato *et al.*, 1989) and hence a high capacity for evaporative heat loss. However, little is known about changes in skin temperature of the foot particularly during intermittent exercise when there is a greater increase in core and skin temperature compared with continuous exercise (Cable and Bullock, 1995).



Clothing, including footwear, acts as a barrier to thermoregulation and affects heat transfer. Thermal discomfort of the feet, due to build up of heat and accumulation of sweat on the skin surface (Winslow *et al.*, 1937; Winslow *et al.*, 1939; Nielsen and Endrusick, 1990), may be a difficulty for athletes. Information about changes in skin temperature of the foot may be of considerable importance to footwear manufacturers and athletes, as problems with comfort can have ramifications for performance.

Therefore the aim of this study was to measure changes in foot skin temperature during both continuous and soccer-specific intermittent exercise whilst wearing footwear.

#### **4.1.2 Research Hypotheses**

Hypothesis 1: Localised foot skin temperature is greater during intermittent exercise than continuous exercise of the same overall intensity.

Hypothesis 2: Mean skin temperature ( $\bar{T}_{sk}$ ) is greater during intermittent exercise than continuous exercise of the same overall intensity.

#### **4.1.3 Methods**

Two trials were carried out with 12 subjects (9 male and 3 female) aged from 19 to 33 years. The characteristics of the participants are displayed in Table 4.1. The subjects were in good health, regularly participated in exercise and freely volunteered for the study. All subjects were asked to refrain from the usual stimulants and stressors as detailed in Chapter 3 (page 75).



**Table 4.1.** Mean (*s*) and range of the subject group characteristics.

Treatment Group	Age (years)	Height (m)	Mass (kg)	Shoe Size
Intermittent	25 ± 3	1.79 ± 0.06	81.0 ± 8.2	9 ± 1
(range)	(19 - 27)	(1.73 - 1.88)	(72.0 - 95.5)	(7 - 11)
Continuous	25 ± 5	1.72 ± 0.05	69.9 ± 10.7	7 ± 1
(range)	(19 - 33)	(1.66 - 1.79)	(54.0 - 81.0)	(5 - 8)

The experimental design consisted of two exercise protocols. One group ( $n = 6$  ♂) followed a soccer-specific intermittent protocol and the other ( $n = 3$  ♀,  $3$  ♂) performed a continuous protocol, both on a motorised treadmill. Both protocols were performed at the same average exercise intensity ( $12 \text{ km h}^{-1}$ ). The intermittent protocol was previously devised to simulate soccer match-play (Drust, 1997). The first 20 minutes of the protocol, illustrated in Figure 3.1, were used to represent the actions of a soccer player during match-play.

Skin temperature measurements (as previously discussed on page 76) were taken at 3 sites on the foot (toe, instep, ankle) and at 4 other sites on the body (chest, arm, thigh, shin) to calculate a weighted mean skin temperature (Ramanathan, 1964). All measurements were taken on the left hand side of the body and thermistors were attached using white surgical adhesive tape (Transpore, 3M, Michigan, USA). The anatomical location of the thermistors is specified in Table 3.1.

The subjects were clothed in shorts, T-shirt, ankle socks and underwear. Prior to the test start, thermistors were allowed to equilibrate for 30 minutes while the subject rested. All subjects were familiar with running on a motorised treadmill. Environmental conditions were held relatively constant ( $22 \pm 2^\circ\text{C}$  and  $45 \pm 5\%$  relative humidity).

Results of the study were examined for the possible significant effects of intermittent exercise compared to continuous exercise on foot skin temperature. Physiological



measurements recorded showed similar responses within conditions. Results are presented as mean values of the two groups.

Analysis of the results was carried out with two methods. Skin temperatures and heart rates were analysed using ANOVA and skin temperatures were also examined using analysis of serial measurements (Mathews *et al.*, 1990) where the change from baseline to end-of-test was analysed using a t-test.

#### **4.1.4 Results**

Averaged 60-s data comparing heart rate values during intermittent and continuous conditions are displayed in Figure 4.1. At the onset of exercise the heart rate increased and during continuous exercise a steady state was attained within 2 minutes with a mean heart rate of 151 beats min<sup>-1</sup>. During intermittent exercise heart rate fluctuated between a mean maximum of 176 and mean minimum of 127 with an overall mean heart rate (from 2 minutes to end of test) of 157 beats min<sup>-1</sup>. Mean heart rate showed no significant difference between conditions ( $P = 0.07$ ).



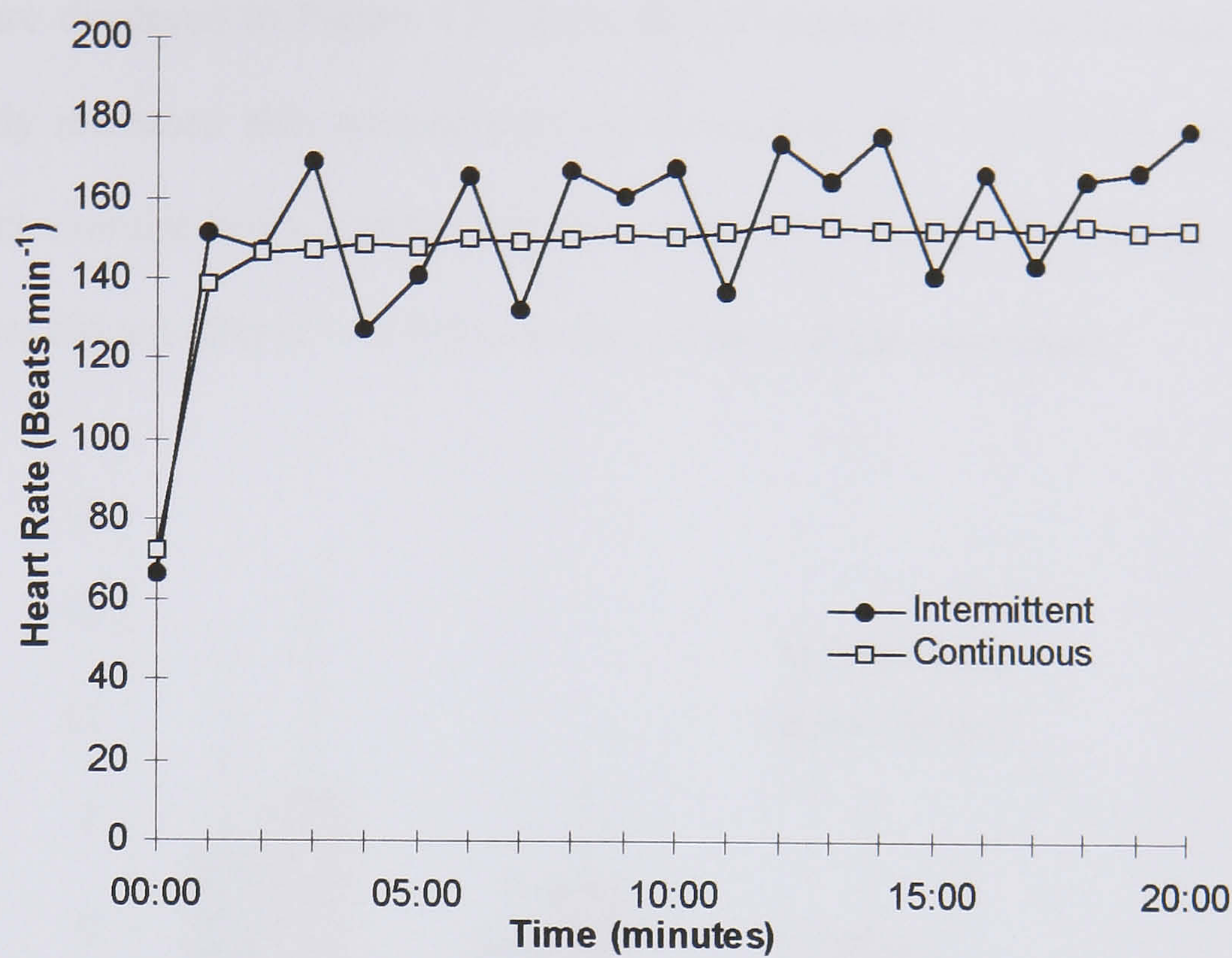


Figure 4.1. Mean heart rate during exercise tests.

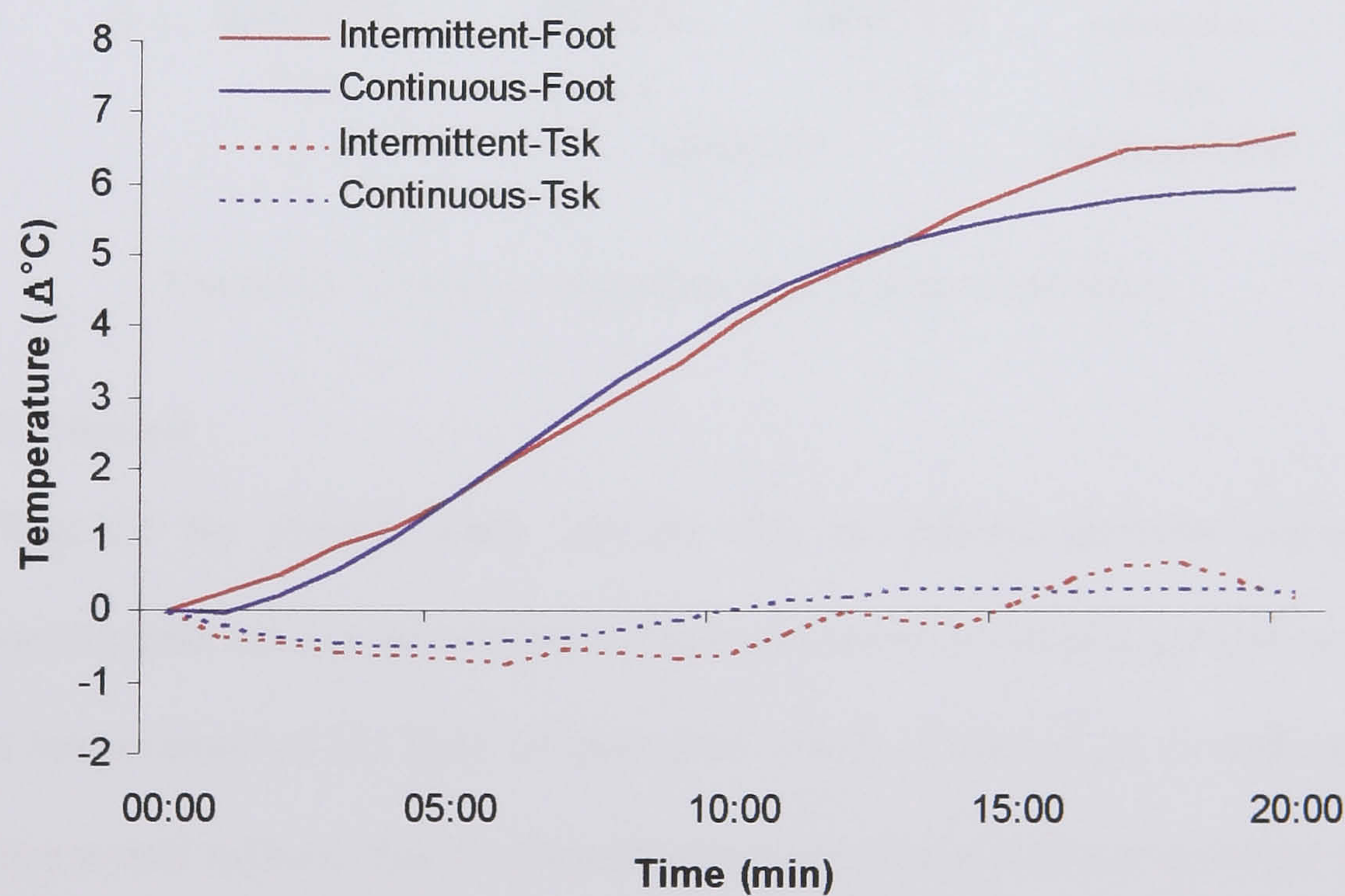
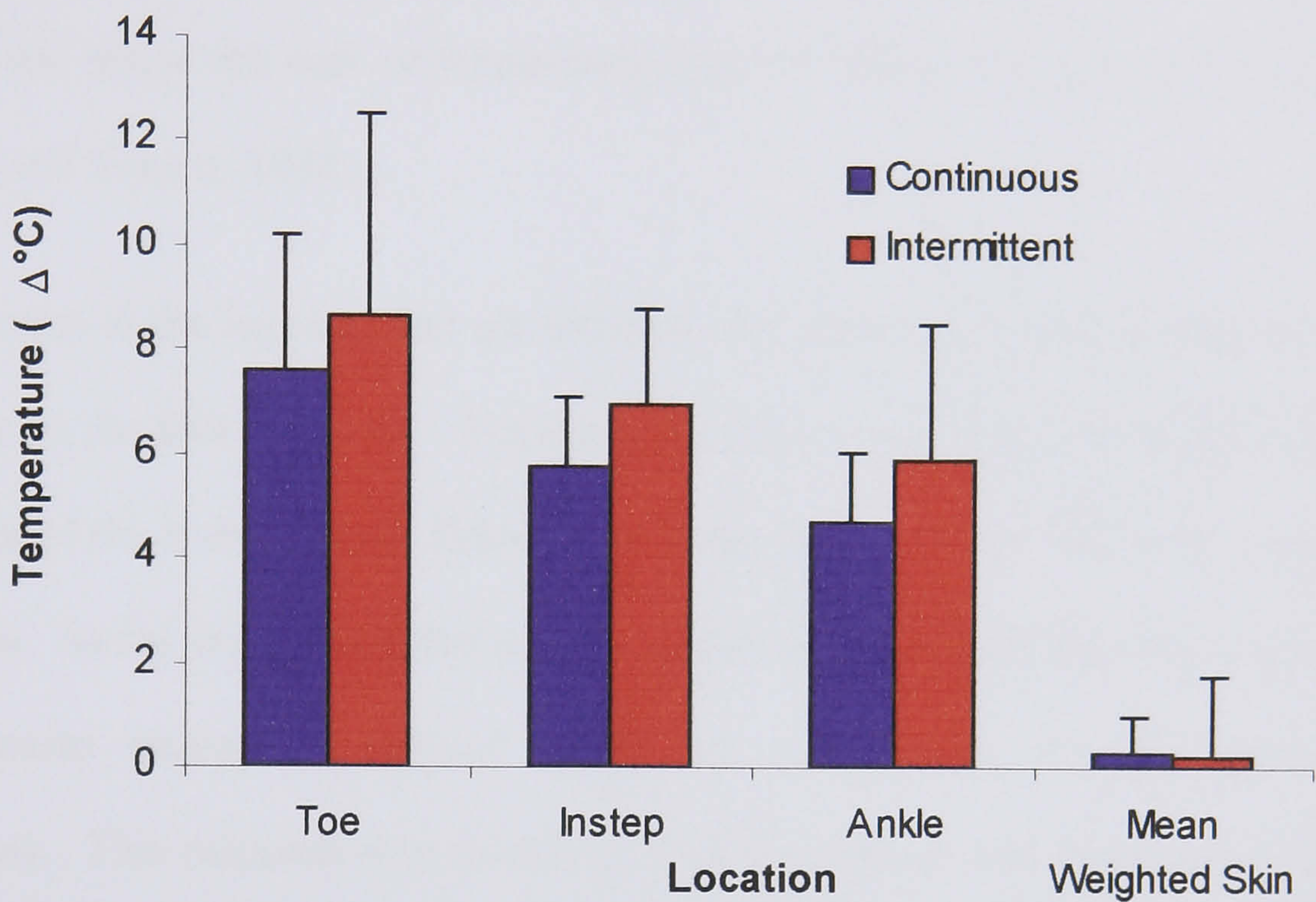


Figure 4.2. Overall mean change in foot temperature compared to mean change in weighted skin temperature ( $\overline{T}_{sk}$ ) during intermittent and continuous activity.

Mean temperature changes at the foot and weighted mean skin temperature are displayed in Figure 4.2. The changes in foot and mean skin temperature from baseline to the end of



exercise are displayed in Figure 4.3. Each site of measurement on the foot showed a significantly increased skin temperature above baseline ( $P < 0.05$ ) with values during intermittent exercise being significantly the greater ( $P < 0.05$ ). In contrast, mean skin temperature did not alter ( $P > 0.05$ ) over the duration of the experiment.



**Figure 4.3.** Change in temperature from baseline to end of test.

**4.1.5 Discussion**

The findings of the present study indicate that intermittent exercise compared to continuous exercise induces an increase in foot skin temperature of a greater magnitude. The high temperature of the foot compared to a lack of change of overall mean skin temperature would indicate that the foot maintains an altered thermoregulatory response not evident elsewhere on the human body. Jeong and Tokura (1989; 1993) examined the effect of clothing coverage. Coverage of all of the body with exception of the head caused a significantly greater core and skin temperature compared to the same fabric covering most the body but not head, hands or feet. The findings also suggested there was a significant role of the extremities in the mechanisms of thermoregulation as rectal



temperature decreased much more quickly following exercise in the total coverage garment than the garment not covering the extremities. The localised skin temperature of the extremities remained elevated for longer in the total coverage garment post-exercise, suggesting that peripheral vasodilation in the extremities contributed to a heat exchange resulting in a faster reduction in core temperature during recovery (Jeong and Tokura, 1989) and hence the lack of whole-body thermal strain when extremities are covered (Jeong and Tokura, 1993).

As muscles in the legs and feet are active during running, the temperature of the blood flowing to the foot increases. The toe is the most distal site of measurement from the opening of the training shoe, followed by instep and lastly the ankle site nearest to the opening. As the site of measurement approaches the opening of the shoe at the ankle, the temperature increase is reduced (albeit not significantly,  $P > 0.05$ ) as ventilation increases. This response was evident in both intermittent and continuous exercise. It appears that the surrounding of the foot by footwear generates an enclosed microenvironment that attenuates the processes of radiative, convective, conductive and evaporative heat loss. Clothing and footwear also increase insulation by creating a trapped insulative layer of air between the skin and fabric or material layer. Evaporative heat loss is further impeded due to absorption of sweat into the sock and shoe. Areas of the foot nearer to the opening of the footwear are cooler due to more air movement and increased convective and evaporative heat loss. Adams et al. (1992) showed that skin temperature was significantly increased in conditions of low air movement compared to high air movement.



Temperature may also be elevated within the shoe due to friction. Friction can be caused by two mechanisms, movement of the foot within the shoe and also shoe-surface contact conducting heat into the shoe (Lees and Thornley, 1990).

Soccer specific exercise is essentially intermittent with maximal sprints interspersed on a framework of lower intensity endurance exercise. Superimposed on this are the ball skills necessary to play the game of soccer. Laboratory simulations are unable to include ball skills. However, research has indicated that physiological responses are similar in magnitude to those observed in match-play conditions (Drust, 1997). Indeed, heart rates recorded during intermittent exercise in this study (Figure 4.1) reflect heart rate profiles reported in previous work (Bangsbo, 1994b; Drust, 1997).

This study demonstrates a greater localised skin temperature of the foot during the soccer specific protocol compared to the continuous protocol, therefore Hypothesis 1 was accepted. The results suggest that footwear may have ramifications for thermal comfort of the player and footwear manufacturers may need to incorporate the use of moisture and heat management materials into boot designs in order to facilitate heat loss. To investigate the effects of footwear during exercise further, the next study examines the effects of different soccer footwear and sock materials on foot skin temperature.



## 4.2 EFFECTS OF FOOTWEAR ON FOOT SKIN TEMPERATURE DURING EXERCISE: AN EVALUATION OF SOCCER FOOTWEAR

### 4.2.1 Introduction

Physiological demands of high intensity intermittent exercise are complex and are dependent upon the pattern of work and recovery periods (Balsom *et al.*, 1992). Soccer match-play requires a player to be able to perform prolonged exercise, superimposed with bouts of maximal intensity anaerobic exercise during sprints and produce high power muscular force during activities such as kicking, jumping and tackling (Bangsbo, 1994b). Extraneous factors, such as environment, altitude, nutrition and clothing, influence performance during soccer. Many soccer tournaments occur in hot environments. Ambient temperatures of greater than 25°C are often experienced and combined with high levels of relative humidity, performance can be impaired and total distance covered during a game can be reduced by as much as 50% (Drust *et al.*, 1998a).

Exercise in the heat may cause individuals to suffer from heat stress, which is detrimental to performance and health. Heat dissipation is dependent upon the temperature difference between the skin and the ambient air. Clothing confounds the heat transfer from the core to the environment (Pascoe *et al.*, 1994a; Pascoe *et al.*, 1994b). Even in a neutral environment certain clothing materials and ensembles can function as a microenvironment of high heat and humidity (Sullivan and Mekjavic, 1992). The development of new fabrics for use in specific environments has provided enhanced heat balance and greater thermal comfort for the wearer. Examination of materials used in socks has received limited attention (Davis, 1975), a running shoe air circulation system has been tested (Lees and Thornley, 1990) and materials used in training shoe outers has



been evaluated (Kawabata and Tokura, 1993). Therefore, this study is unique as the effects of footwear have largely been ignored in clothing research.

Soccer footwear may improve or diminish the performance of a player. This study was carried out to examine the effects of different footwear and sock materials, currently manufactured, on foot skin temperature and investigate any impact on whole-body thermoregulation and energy expenditure. The footwear included soccer training shoes, soccer studded boots, *Metcradle* insoles (designed to protect the first metatarsal head from injury due to repeated impacts), *Comformax* (sweat wicking) socks and nylon socks.

#### 4.2.2 Research Hypotheses

Hypothesis 3: During exercise the increase in temperature of the foot is significantly larger than mean skin temperature ( $\bar{T}_{sk}$ ).

Hypothesis 4: The increase in foot skin temperature is significantly greater when wearing soccer studded boots compared to soccer training shoes.

Hypothesis 5: The increase in foot skin temperature is significantly greater when wearing soccer studded boots compared to soccer studded boots with *Metcradle* insoles.

Hypothesis 6: Accumulation of sweat in *Comformax* socks is significantly lower than that in nylon socks.



### 4.2.3 Methodology

#### 4.2.3.1 Subjects

Experiments were conducted on six healthy male university students, who were moderately active, participating in soccer training a minimum of once a week. Three of the subjects were university league players, two played both in university league and occasional semi-professional games and one played at a recreational level. All subjects were considered to be non-acclimatised to any environmental extremes. The mean physical characteristics of the subjects were measured on the first visit to the laboratory and are shown in Table 6.1. All subjects were given written information concerning the nature, purpose, practical details, risks and procedures of the study and all freely volunteered for the study. Written informed consent was obtained from each of the participating individuals. The study was approved by the Human Ethics Committee at Liverpool John Moores University and conforms to all policy regarding the use of human subjects.

**Table 4.2.** Mean (*s*) and range of subject group characteristics.

	Age (years)	Mass (kg)	$\dot{V}O_{2\max}$ (ml kg <sup>-1</sup> min <sup>-1</sup> )	% Body Fat	BMI	Surface Area (m <sup>2</sup> )	Foot Size (UK)
Mean	23	72.4	56.2	13.5	23.7	1.87	8.2
<i>s</i>	5	7.4	2.5	4.6	1.5	0.11	0.3
Range	19 - 32	62.5 - 81.8	53.6 - 59.7	6.0 - 19.2	21.6 - 25.8	1.72 - 1.99	8.0 - 8.5

#### 4.2.3.2 Exercise and Environmental Conditions

The experiments were conducted in an environmental chamber with temperature and humidity levels closely monitored and controlled. The mean ambient temperature was  $21.0 \pm 1.0^{\circ}\text{C}$  with a relative humidity of  $45.0 \pm 5.0\%$ .



Each participant visited the laboratory on four separate occasions, a minimum of one week apart and individually conducted at the same time of day to eliminate any circadian variation in performance or thermoregulatory response. An initial  $\dot{V}O_{2\text{ max}}$  assessment was followed by three experimental test conditions. The subject's  $\dot{V}O_{2\text{ max}}$  was recorded using a continuous incremental test on a motorised treadmill (Quinton Instruments, Seattle, USA). Gas was analysed using a breath-by-breath mass spectrometer system (Morgan Medical, Rainham, Kent, UK) with measurements calculated every 15 seconds. All gas volumes were corrected to STPD.

Each subject then returned to the laboratory on three further occasions and was asked to perform 46 min 10 s of intermittent exercise in neutral environmental conditions described above. Prior to each of the experimental sessions, the subjects were asked to refrain from the usual stimulants (detailed on page 75). The footwear conditions were administered to subjects using a Latin square crossover randomisation design. Drust's (1997) soccer-specific intermittent protocol was utilised (illustrated in Figure 3.1). All subjects were familiarised with running on a motorised treadmill and the equipment used. All three conditions required subjects to wear a nylon football sock on one foot and a *Comformax* football sock on the opposite foot. Three types of footwear were tested with the same sock arrangement; trainers, moulded Umbro *Speciali* soccer boots and boots with Umbro *Metcradle* inserts.



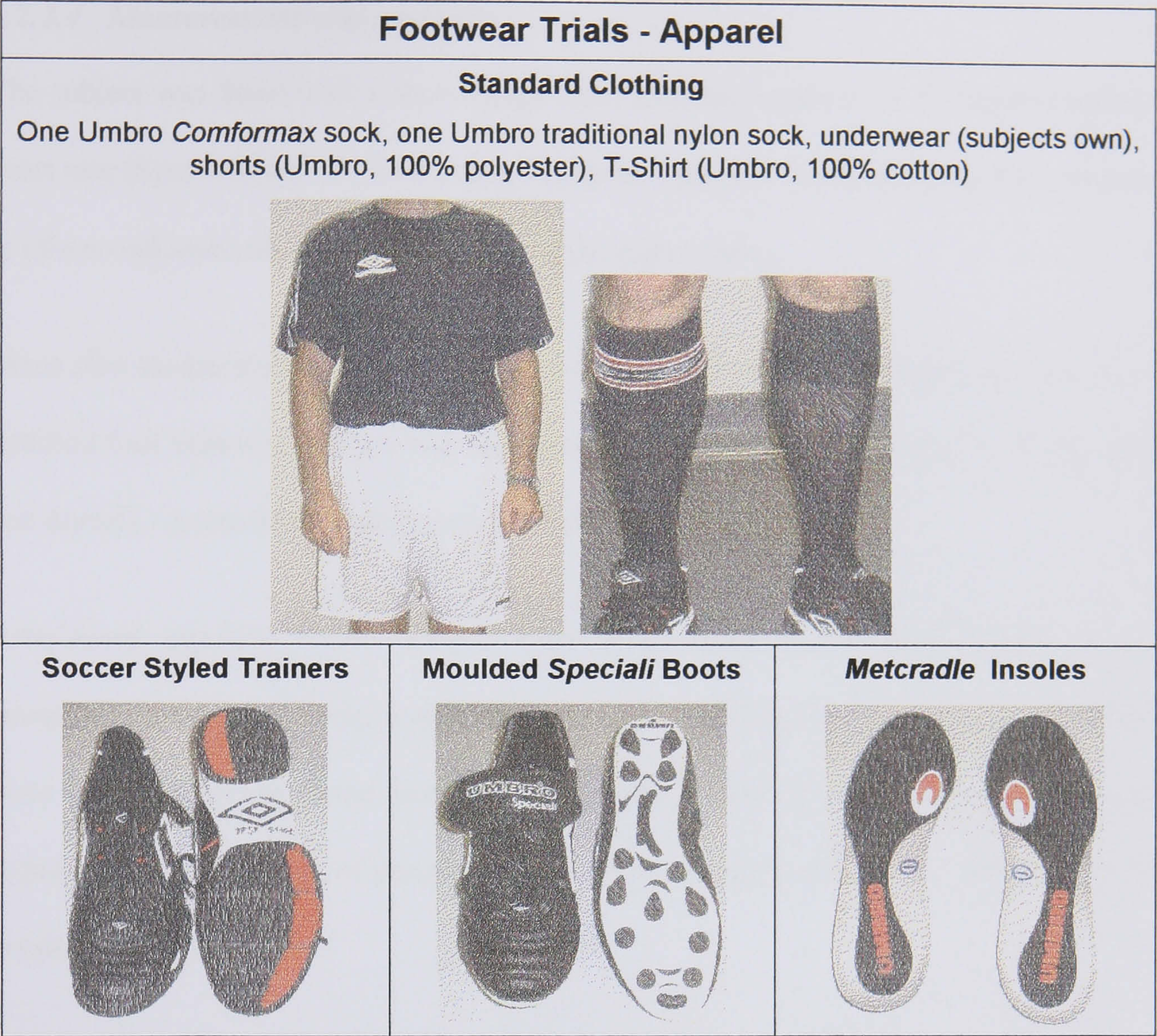


Plate 4.1 Clothing and equipment worn in footwear trials.

4.2.3.3 Procedures

On the day of each trial, the subject reported to the laboratory 30 minutes prior to the trial beginning. Participants wore the same clothing ensemble for each session, which comprised underwear, Umbro polyester shorts and Umbro cotton T-shirt. Prior to testing, and upon completion, the subjects weighed themselves nude. Following the initial weighing the participant inserted a rectal temperature probe to a depth of 10 cm beyond the anal sphincter to allow continuous measurement of core temperature. The participant then rested in a seated position for 20 minutes during which time the thermistors were placed upon the skin with sterile surgical adhesive tape (Transpore, 3M, Michigan, USA).



#### 4.2.3.4 *Measurements and Analysis*

The subject was fitted with a short-range radio telemetry system for the measurement of heart rate (Sports Tester, Polar Electro, Kempele, Finland). Measurements were recorded at 60-second intervals during the period of the experiment.

Mean skin temperature was measured according to the methods detailed on page 77. In addition foot skin temperature was measured at four sites on each foot (toe, instep, ankle and dorsal). Anatomical positioning is detailed in Table 3.1.

Arterialised capillary blood samples were taken from a pre-warmed hand on four occasions: pre-test, mid-test, immediately post-test and 5 minutes post-test. The samples were used to analyse blood lactate. During the period of exercise participants were requested to give ratings of perceived exertion on a scale between 1 to 10 (Borg, 1970) detailed on page 78.

#### 4.2.3.5 *Statistical Analysis*

A two-way two-factor ANOVA for repeated measures was applied to determine any treatment differences during the exercise protocol. Analysis of serial measurements was also used (Mathews *et al.*, 1990) to separately analyse the change in temperature for each site in each condition. This method uses a paired t-test to examine the changes within a variable from baseline to end-of-test. In all tests a *P* value of 0.05 or less was considered to be significant.

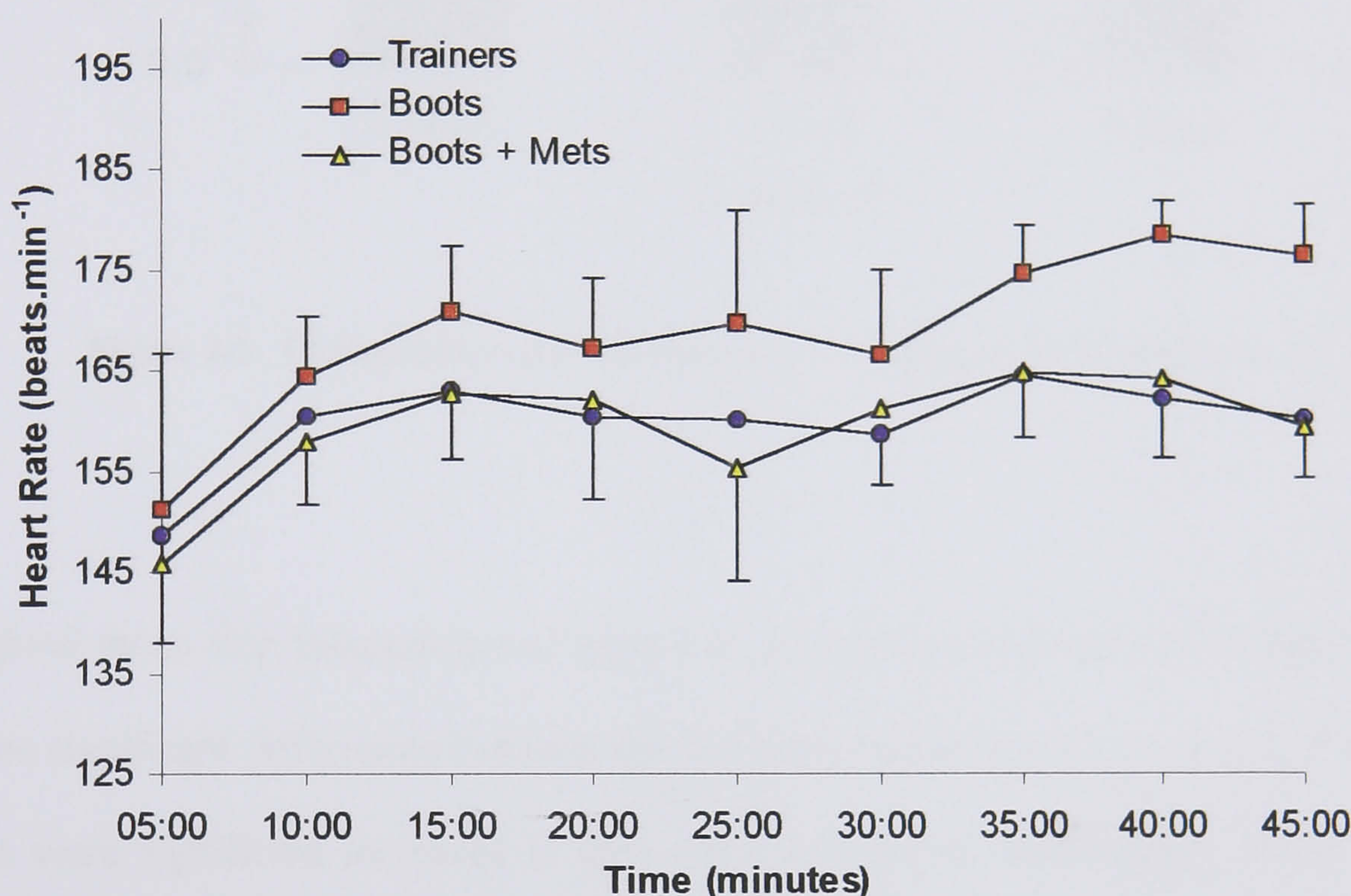
### 4.2.4 **Results**

#### 4.2.4.1 *Cardiovascular Responses.*

Heart rate increased at the onset of exercise at the same rate for all three footwear conditions (Figure 4.4). The overall mean heart rate during exercise was



$160 \pm 20$  beats  $\text{min}^{-1}$ ,  $169 \pm 18$  beats  $\text{min}^{-1}$  and  $158 \pm 20$  beats  $\text{min}^{-1}$  for trainers, boots and boots with *Metcradles* respectively. The differences found were not statistically significant between the footwear conditions ( $F_{2,8} = 0.53$ ,  $P = 0.533$ ) although there were significant increases over the duration of the exercise ( $F_{4,16} = 4.65$ ,  $P = 0.011$ ). No interaction between footwear and time was found ( $F_{2.48, 9.93} = 1.11$ ,  $P = 0.380$ ).

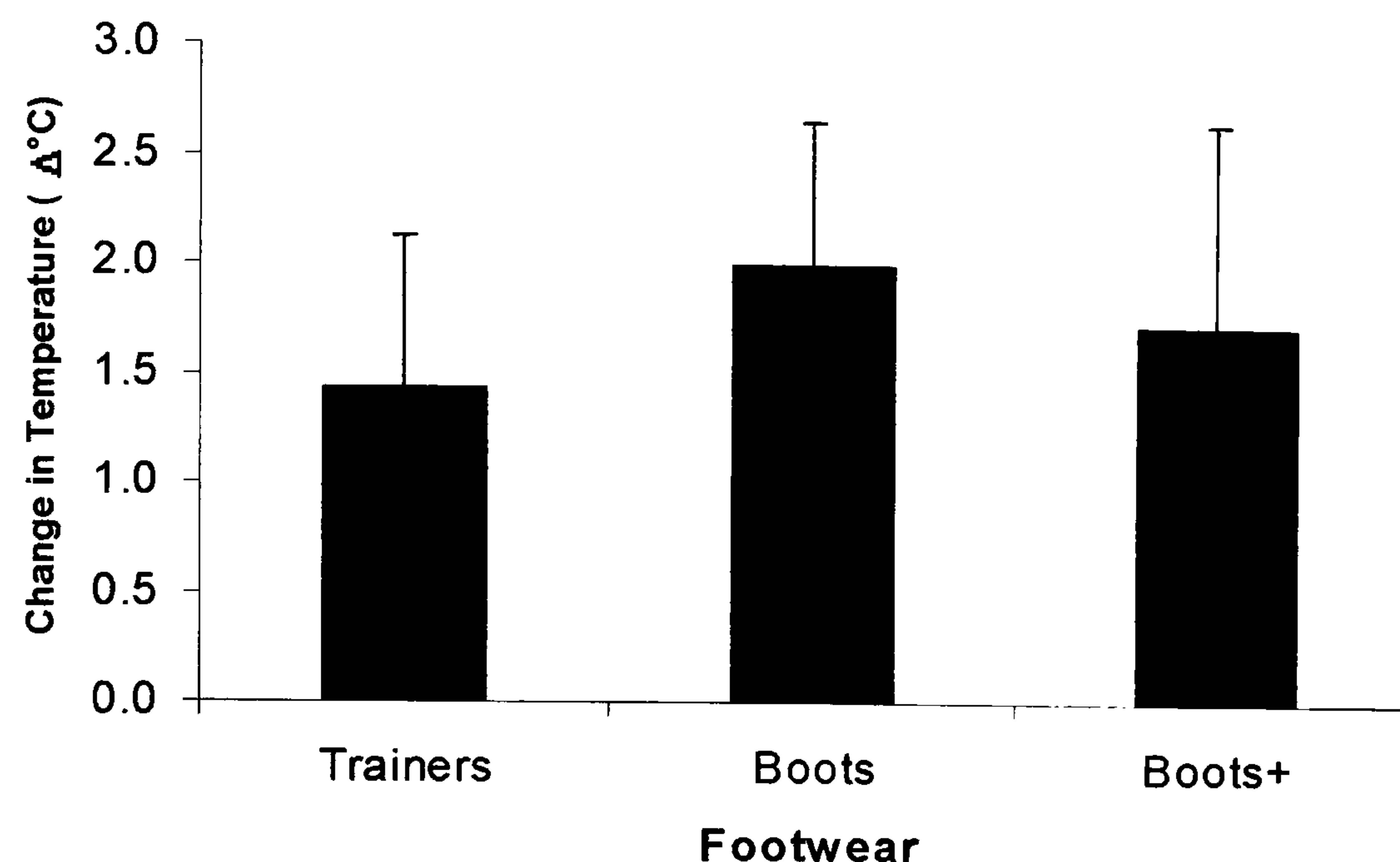


**Figure 4.4.** Mean (s) heart rate values during exercise under the three footwear treatments.

#### 4.2.4.2 Thermoregulatory Responses

Core (rectal) temperature was not influenced by the footwear worn ( $F_{1.011, 3.032} = 1.002$ ,  $P = 0.391$ ). Change in temperature from baseline to end-of-exercise was also not significant ( $F_{1.13, 3.39} = 0.306$ ,  $P = 0.641$ ). However, there was a slightly larger increase above that when wearing trainers, of  $0.6^{\circ}\text{C}$  and  $0.3^{\circ}\text{C}$  for boots and boots with *Metcradles* respectively (Figure 4.5). No interaction of footwear and time resulted ( $F_{1.01, 3.03} = 0.950$ ,  $P = 0.402$ ).





**Figure 4.5.** Change in core (rectal) temperature from baseline to end-of-exercise.

Weighted mean skin temperature (Figure 4.8) increased significantly over time but there was no significant differences between the footwear conditions ( $F_{2,8} = 1.111$ ,  $P = 0.376$ ). There were significant increases in skin temperature over the duration of the exercise ( $F_{2,44,9.75} = 9.77$ ,  $P = 0.004$ ) but no interaction between the main effects ( $F_{8,32} = 0.210$ ,  $P = 0.987$ ).

Figure 4.6 displays absolute skin temperature of the foot presented as a mean of all four sites measured during each footwear condition. Statistically there were no significant differences between the footwear conditions. However, generally the *Comformax* performance sock appears to induce a slightly elevated skin temperature for the three types of footwear tested compared to the traditional nylon sock. Figure 4.7 shows the change in temperature from baseline to end of exercise for each individual foot site. All foot sites measured showed a significant increase in skin temperature with time



( $P < 0.05$ ). Significant interactions were found between sock and shoe in the area of the toe ( $P < 0.05$ ) and between sock and time in the area of the ankle ( $P < 0.05$ ).

**Table 4.3.** Results of ANOVA examining regional skin temperatures.

	Toe	Instep
<i>Region of Foot</i>		
Sock	$F_{1,4} = 3.35, P = 0.141$	$F_{1,4} = 0.11, P = 0.761$
Shoe	$F_{1.17, 4.69} = 0.37, P = 0.604$	$F_{2,8} = 0.02, P = 0.980$
Time	$F_{1.45, 5.79} = 73.76, P = 0.000 **$	$F_{2.08, 8.33} = 38.85, P = 0.000 **$
sock $\times$ shoe	$F_{2,8} = 4.30, P = 0.054 *$	$F_{2,8} = 0.35, P = 0.717$
sock $\times$ time	$F_{4,16} = 2.66, P = 0.071$	$F_{1.27, 5.10} = 1.17, P = 0.349$
shoe $\times$ time	$F_{2.28, 9.13} = 0.70, P = 0.541$	$F_{2.93, 11.73} = 0.82, P = 0.507$
sock $\times$ shoe $\times$ time	$F_{2.03, 8.10} = 0.81, P = 0.480$	$F_{1.14, 4.58} = 0.92, P = 0.400$
	Ankle	Dorsal
<i>Region of Foot</i>		
sock	$F_{1,4} = 5.98, P = 0.071$	$F_{1,3} = 0.10, P = 0.776$
shoe	$F_{1.22, 4.87} = 0.23, P = 0.695$	$F_{2,6} = 0.93, P = 0.444$
time	$F_{4,16} = 96.41, P = 0.000 **$	$F_{4,16} = 171.36, P = 0.000 **$
sock $\times$ shoe	$F_{2,8} = 0.66, P = 0.541$	$F_{2,6} = 1.04, P = 0.411$
sock $\times$ time	$F_{4,16} = 2.99, P = 0.051 *$	$F_{1.45, 4.34} = 0.88, P = 0.440$
shoe $\times$ time	$F_{5.92, 23.68} = 0.28, P = 0.938$	$F_{4.07, 12.22} = 1.11, P = 0.398$
sock $\times$ shoe $\times$ time	$F_{3.09, 12.37} = 0.93, P = 0.446$	$F_{2.83, 8.48} = 1.32, P = 0.329$
* = $P < 0.05$ , ** = $P < 0.001$		

Tukey's HSD tests showed that toe temperature was greater when wearing the performance sock in trainers compared to the traditional sock worn with boots and metcradles. The toe skin temperature when wearing the traditional sock worn with boots and insoles was less than the toe skin temperature when wearing the performance sock worn with boots. Additionally, the performance sock worn in boots invoked a greater toe skin temperature than when wearing the performance sock in boots with insoles.

Tukey's HSD tests showed that the differences in ankle temperature were not particularly relevant, for example, the ankle temperature at 5 min when wearing a traditional sock was



less than the ankle temperature when wearing a performance sock at 15 min, 20 min, 25 min, 30 min, 35 min, 40 min, 45 min and at the end of exercise.



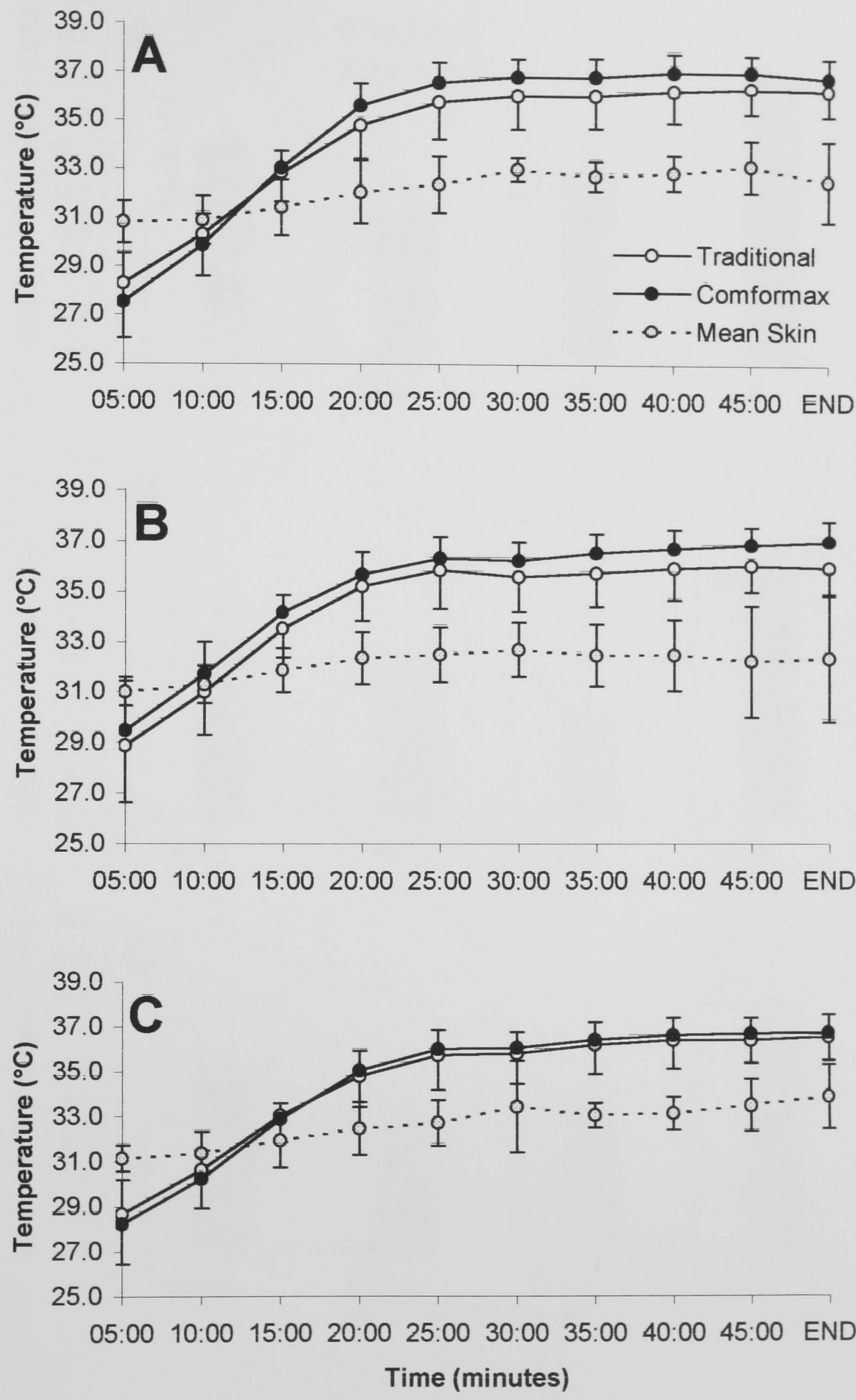
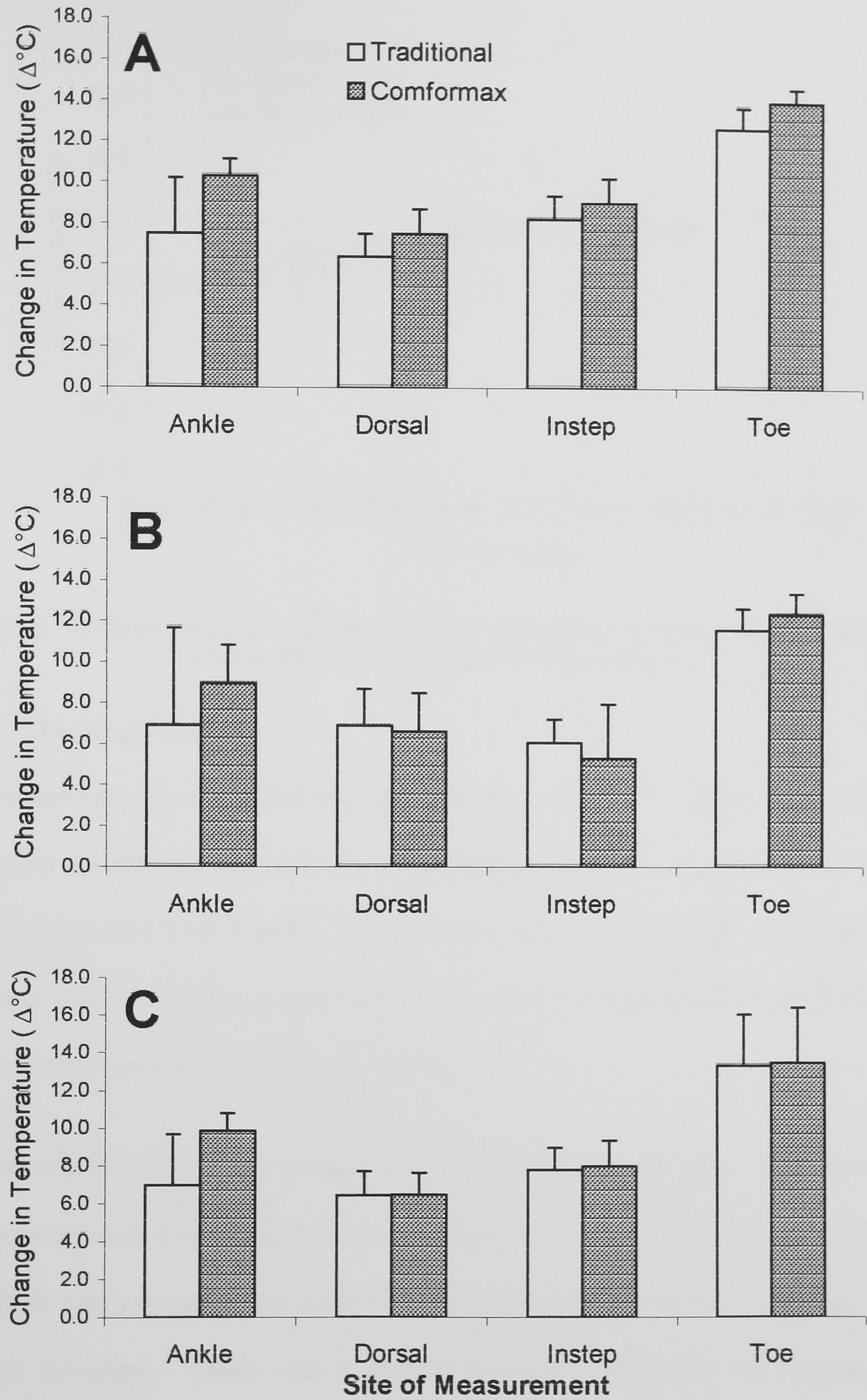


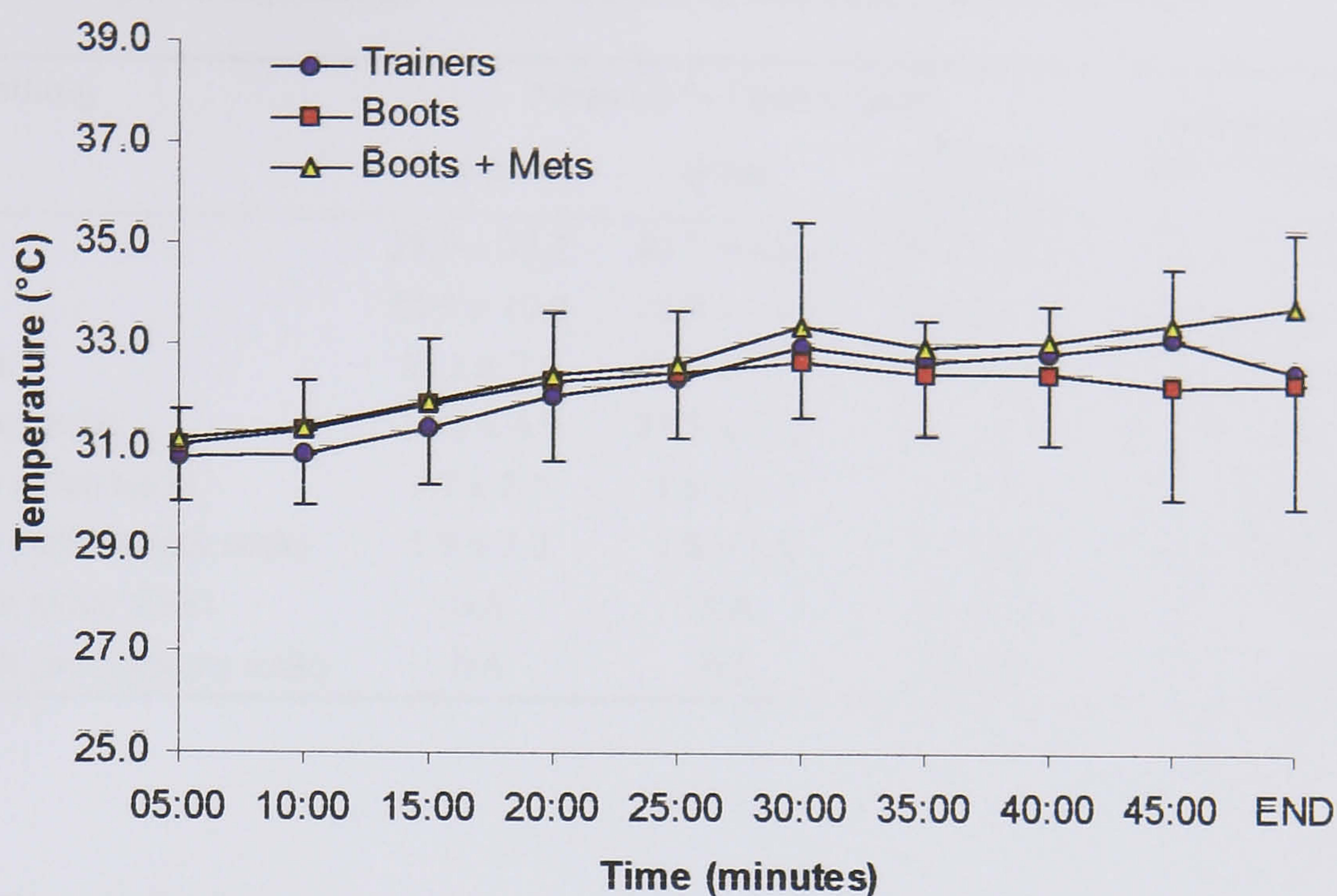
Figure 4.6. Mean overall foot skin temperature when wearing trainers (A), soccer boots (B) and soccer boots with *Metcradle* insoles (C), comparing effects of the two sock materials.





**Figure 4.7.** Mean change in individual foot skin temperature sites when wearing trainers (A), soccer boots (B) and soccer boots with *Metcradle* insoles (C), comparing effects of the two sock materials .





**Figure 4.8.** Weighted mean skin temperature during exercise for the three footwear conditions. There were no significant differences between treatments.

#### 4.2.4.3 Sweating Responses

Mean sweat rate was estimated with the assumption that sweat gland output was linear throughout the test and respiratory water loss was not taken into consideration. Sweat rate was calculated as  $1.4 \pm 0.5 \text{ kg h}^{-1}$ ,  $1.5 \pm 0.4 \text{ kg h}^{-1}$  and  $1.4 \pm 0.7 \text{ kg h}^{-1}$  for trainers, boots and boots with *Metcradles*, respectively. There were no significant differences between footwear conditions ( $F_{2, 10} = 1.77$ ,  $P = 0.220$ ).

Apparel and footwear were weighed immediately before and after each exercise test session to determine sweat accumulation. Mean percentage changes are given in Table 4.4. There was a large amount of between-subject variability, which is evident in the high standard deviation. There was a general trend ( $P > 0.05$ ) for the greatest sweat accumulation in apparel during the trial of boots with *Metcradles* and least accumulation when wearing trainers. None of the participants accumulated any sweat in the *Metcradle* insoles. Higher sweat absorption occurred in the *Comformax* sock compared to the traditional nylon sock in all three footwear conditions.



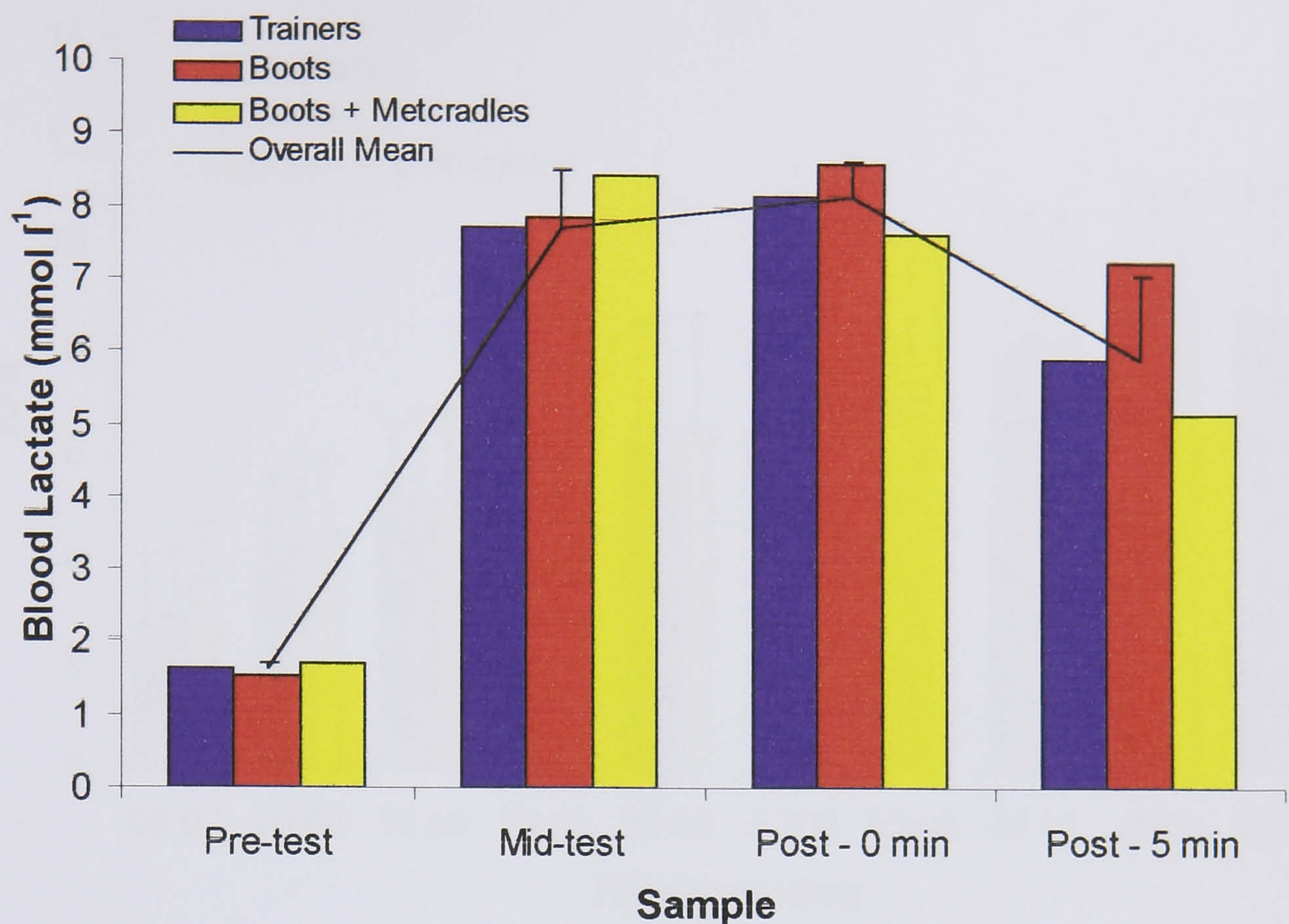
**Table 4.4.** Mean percentage change in mass of clothing items due to sweat production.

Item of Clothing	Mean (s) % Gain in Mass			Statistical differences between footwear trials
	Trainers	Boots	Boots + <i>Metcradles</i>	
T-shirt	39.9 ± 35.1	49.7 ± 43.4	54.4 ± 50.6	$F_{2,10} = 1.77, P = 0.220$
Shorts	12.9 ± 10.2	18.8 ± 15.2	22.0 ± 21.8	$F_{2,10} = 1.78, P = 0.218$
Nylon Sock	15.1 ± 7.6	20.7 ± 15.4	24.1 ± 18.9	$F_{2,10} = 1.33, P = 0.308$
Performance Sock	13.6 ± 6.9	23.7 ± 20.3	21.6 ± 15.6	$F_{2,10} = 1.75, P = 0.223$
Shoe (with nylon sock)	1.7 ± 2.0	1.5 ± 1.3	1.2 ± 1.9	$F_{2,10} = 0.957, P = 0.417$
Shoe (with performance sock)	1.9 ± 2.0	1.8 ± 1.8	1.7 ± 2.1	$F_{2,10} = 0.845, P = 0.458$
Insole (with nylon sock)	NA	NA	0.0 ± 0.0	NA
Insole (with performance sock)	NA	NA	0.0 ± 0.0	NA

#### 4.2.4.4 Metabolic Responses

No significant footwear condition differences were found in blood lactate concentrations at rest, during exercise or post-exercise ( $F_{2,10} = 0.532, P = 0.603$ ), however, there was an effect of time ( $F_{1.91,9.54} = 13.371, P = 0.002$ ) illustrated in Figure 4.9. No interaction between main effects was found ( $F_{6,30} = 1.655, P = 0.171$ ).



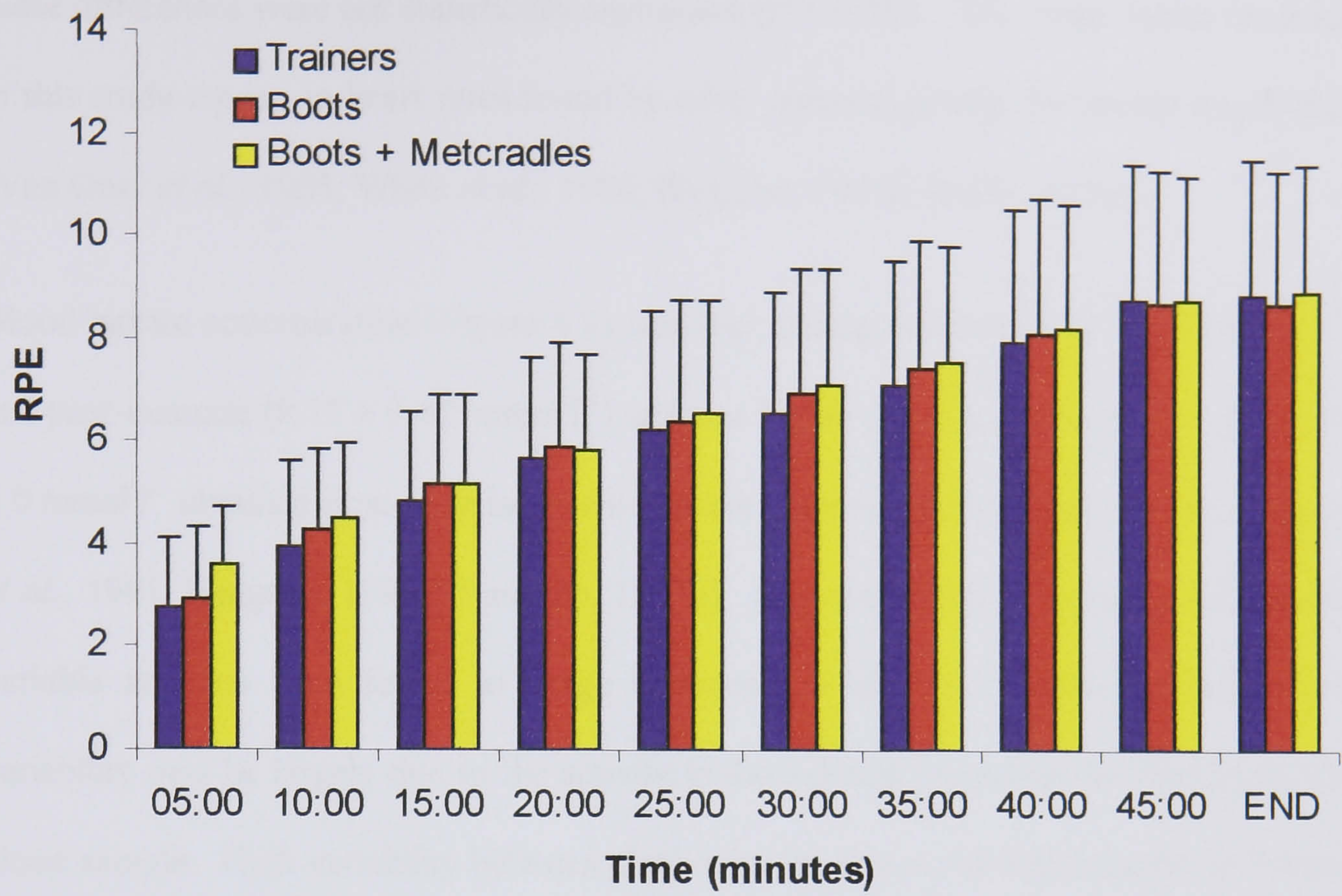


**Figure 4.9.** Mean (s) blood lactate concentrations at rest (pre-test), during exercise (mid-test), immediately after exercise (Post - 0 min) and 5 minutes following exercise (Post - 5 min). All exercise values are significantly higher than rest ( $P < 0.05$ ).

4.2.4.5 Subjective Responses

Overall mean ratings of perceived exertion (Figure 4.10) were identical at  $6 \pm 3$  for all footwear conditions. This RPE value equates to a perceived exercise intensity of 'hard'. There was a trend for the RPE to increase with exercise duration and all initial ratings were lower than the ratings recorded at the end of exercise. There were no significant differences between conditions ( $F_{1.24, 4.98} = 0.78, P = 0.447$ ) although some small differences between footwear conditions are displayed in Figure 4.10. Most time points show the lowest mean RPE occurred when wearing trainers, followed by boots and with the highest values for Boots with *Metcradles*. The increase in RPE over the duration of the exercise was significant ( $F_{1.33, 5.34} = 20.64, P = 0.004$ ), but there was no interaction between main effects ( $F_{7.08, 28.32} = 0.58, P = 0.765$ ).





**Figure 4.10.** Overall mean (s) rating of perceived exertion during exercise under the three footwear conditions.

**4.2.5 Discussion**

The aim of the present study was to determine the physiological, metabolic and thermoregulatory responses to different types of footwear (sock and shoe) whilst performing soccer-specific intermittent exercise on a motorised treadmill.

*4.2.5.1 Physiological and Metabolic Responses*

Some differences in heart rate were found between footwear conditions. Trainers and boots with *Metcradle* insoles were found to evoke a lower heart rate ( $160 \pm 20$  beats  $\text{min}^{-1}$  and  $158 \pm 20$  beats  $\text{min}^{-1}$ , respectively) than when soccer boots alone were worn ( $169 \pm 18$  beats  $\text{min}^{-1}$ ). However, a difference of approximately 10 beats  $\text{min}^{-1}$  is relatively small considering the duration and intense nature of the exercise; furthermore



these differences were not statistically significant ( $P > 0.05$ ). The mean values recorded in this study equate to heart rates found by other research groups for soccer match-play (Van Gool *et al.*, 1988; White *et al.*, 1988; Bangsbo, 1994b; Reilly, 1996c).

Blood lactate concentration (Figure 4.9) was high during exercise ( $7.73 \pm 0.77 \text{ mmol l}^{-1}$ ) and post-exercise ( $8.15 \pm 0.47 \text{ mmol l}^{-1}$ ) and was higher than the concentration of around  $5.0 \text{ mmol l}^{-1}$  obtained post-exercise in elite soccer players (Nielsen *et al.*, 1989; Bangsbo *et al.*, 1991; Bangsbo, 1994a; Bangsbo, 1994b). Post-match blood lactate is individually variable and has been found to range between  $1.0$  and  $14.3 \text{ mmol l}^{-1}$ , although the variability may be largely due to the activity in the 3-5 min preceding the drawing of the blood sample. High variability between players is also due to the high intensity activities, such as the maximal sprints evident in soccer activity, being dependent on an individual's personal motivation, playing style, tactics and strategy (Bangsbo, 1994a) as well as physical capabilities. Elevated lactate could be due to the subjects being university soccer players and not of an elite professional standard. Additional to the anaerobic demands of cruising and sprinting, muscle temperature is elevated during exercise and skin blood flow increases to dissipate the excess heat. Blood flow and hence oxygen supply to the working muscle is reduced which causes a resultant increase in anaerobic metabolism and therefore blood lactate increases (Maxwell *et al.*, 1996).

The protocol appears to provide a similar physiological response to match-play conditions. There were no apparent alterations in physiological responses due to the different footwear worn as there were no significant differences between conditions ( $P > 0.05$ ).



#### 4.2.5.2 Thermoregulatory Responses

The participants all wore identical clothing ensembles during trials to ensure only the different footwear would cause any resultant differences in thermoregulation. An individual's thermal state is determined by factors that influence heat dissipation from the body core to surrounding environment. Clothing, including footwear, has important implications in thermoregulation. The transfer of heat via convection and evaporation between the skin and the environment occurs indirectly through the microenvironment created by wearing clothing (Sullivan and Mekjavic, 1992; Shigaki *et al.*, 1993). Socks and shoes are no exception. The investigation addressed the effects of different types of socks and shoes on local and whole-body thermoregulation in normothermic environmental conditions.

Initially the skin temperature of the foot was lower (overall mean of  $27.9 \pm 3.1^{\circ}\text{C}$ ) than that of the body mean weighted skin temperature ( $31.0 \pm 1.1^{\circ}\text{C}$ ) ( $P < 0.05$ ). This finding is verified by previous research that shows extremities are cooler than the rest of the body when the subject is at rest (Lees and Thornley, 1990). The foot appears to experience dissimilar thermoregulatory features compared with the rest of the body (Hirata, 1988; Jeong and Tokura, 1989; Jeong and Tokura, 1993; Purvis and Cable, 1999).

Despite the differences in the materials and designs used in the socks and shoes, physiological measurements were similar. Although local skin temperature and sweat accumulation in the footwear were not significantly different ( $P > 0.05$ ), disparities between socks and shoes were apparent.

The area of toe consistently showed the greatest change in skin temperature compared with other areas of the foot and this response occurred for each type of shoe and sock (Figure 4.7). The localised temperatures and humidity within clothing have been shown



to be very important in heat exchange and have an overall effect on thermoregulation (Nielsen and Endrusick, 1992; Desruelle *et al.*, 1996).

Skin temperature on the foot wearing the *Comformax* sock was slightly higher in the majority of sites and footwear conditions (overall mean of all sites and conditions was  $34.32 \pm 2.91^{\circ}\text{C}$ ) compared to the nylon sock ( $34.71 \pm 3.07^{\circ}\text{C}$ ) although the differences were not statistically significant ( $P > 0.05$ ). The slight elevations in skin temperature caused by the *Comformax* sock are illustrated in Figure 4.6 and Figure 4.7. The thermoregulatory attributes of the extremities have been shown to vary depending on the type of clothing worn (Hirata, 1988). The sole of the foot has been found to produce large quantities of sweat compared to the rest of the body (Park and Tamura, 1992). Air restriction of footwear causes high sweat production in order to try and maintain body temperature close to  $37^{\circ}\text{C}$ . The weight differences of the socks before testing were approximately 10 g with the performance sock weighing more than the nylon sock. The weight difference may have been the sole factor that caused the differences in temperature. If the two socks were produced with the same thickness, density and weight the differences may not have occurred. However, in this study the differences between currently manufactured footwear were subject to examination.

Increase in local skin temperature causes an increase in local sweat rate (Ogawa, 1984). Therefore, the increase in skin temperature for the *Comformax* sock above that of the nylon sock should cause a greater sweat production upon the *Comformax* foot compared to the nylon foot. However, the nylon sock generally absorbed more sweat (Table 4.4) and all subjects reported that the nylon sock felt damp and often slipped down during running. Most subjects preferred the nylon sock taped at the top using surgical tape to prevent it from slipping down to the ankle. The materials used in the *Comformax* sock



may have been more beneficial for removal of sweat from the skin, through the sock and out into the environment, but less beneficial for actual cooling of the skin. The absorptive properties of a material have an effect on physiological sweating mechanisms (Tokura and Midorkikawa-Tsurutani, 1985; Kakitsuba *et al.*, 1988). Once sweat is absorbed into the sock material, an effect similar to condensation can occur. Water vapour diffuses into the clothing and becomes trapped liberating the heat of vaporisation, which increases the temperature of the clothing. The heat gain in the clothing is then either dissipated to the ambient environment or the microenvironment between the clothing and the skin. An increase in microenvironment heat or humidity can cause an increase in skin temperature or attenuate heat loss from the skin.

The process of evaporation and heat dissipation through clothing is dependent upon several elements. These factors include physical properties of the clothing, design of the clothing (McCullough *et al.*, 1983), clothing fit (Bouskill *et al.*, 1998b), body movement and activity (Nielsen *et al.*, 1985), air velocity (Bouskill *et al.*, 1998a), air temperature and air humidity (Kakitsuba *et al.*, 1988). Although the *Comformax* sock caused the slightly higher local skin temperature (0.39°C greater), it was found to be subjectively more comfortable to wear and stayed up better than the nylon sock on the opposite foot. Previous research has shown that athletes tend to prefer a thicker sock for greater perceived comfort even if an alternative thinner sock kept the feet drier and cooler (Davis, 1975). A softer and dryer feeling sock has also been shown to be perceived as more comfortable by wearers (Morris *et al.*, 1984-1985).

Insulation of a clothing garment is mainly determined by the thickness of the material and trapped air (Bakkevig and Nielsen, 1995). To allow sweat and heated air to escape to the surrounding ambient air the outer clothing layer must be open to the environment



allowing ventilation to remove and dissipate heat to cool the body. Shoes are a relatively impermeable item of apparel and therefore will cause an elevation in local skin temperature (Desruelle *et al.*, 1996). If sufficient body surface remains available for heat dissipation no extra heat storage should occur. Other factors such as exercise intensity, environmental conditions and other garments may prevent adequate heat loss and result in elevated core temperature.

Percentage loss of body mass due to sweat production was not different ( $P > 0.05$ ) between conditions at  $1.5 \pm 0.4\%$ ,  $1.5 \pm 0.5\%$ , and  $1.4 \pm 0.6\%$  when wearing trainers, boots and boots with *Metcradle* insoles, respectively. This amount of dehydration is considered to be relatively mild (Barr, 1999) but even mild dehydration may reduce performance. Mean sweat rate was estimated as  $1.4 \pm 0.5 \text{ kg h}^{-1}$ ,  $1.5 \pm 0.4 \text{ kg h}^{-1}$  and  $1.4 \pm 0.7 \text{ kg h}^{-1}$  for trainers, boots and boots with *Metcradles*, respectively. Using the mean values obtained from the subjects in this study, a player can be expected to lose up to 2.25 kg, the equivalent of a 3.1% reduction in body mass, during a 90-min soccer game. This rate of sweat loss is similar to that found previously (Mustafa and Mahmoud, 1979; Bangsbo, 1994b; Reilly, 1996c) and has been shown to adversely affect performance. Fluid intake prior to a soccer game and fluid replacement strategies during and after play are important to maintain performance and delay the time to fatigue (Maughan and Leiper, 1994; Shi and Gisolfi, 1998; Galloway, 1999). The addition of carbohydrates to fluids may also improve endurance performance during prolonged exercise (Foster *et al.*, 1979; Ivy *et al.*, 1979; Maughan, 1993) such as soccer.

#### 4.2.6 Conclusions

In conclusion, soccer footwear does not have a significantly detrimental effect on physiological responses compared with training shoes. However, there is some evidence



of increased thermal and physiological strain. The soccer boots worn alone effected an elevated ( $P > 0.05$ ) heart rate compared to the trainers and boots with *Metcradle* insoles. It is possible that the *Metcradle* insoles are efficient at reducing impact upon footfall, and hence the friction that generates heat (Lees and Thornley, 1990). A slightly elevated core temperature ( $P > 0.05$ ) also resulted when wearing the soccer boots alone. Skin temperature of the foot was found to be slightly elevated ( $P > 0.05$ ) on the foot wearing the *Comformax* sock compared to the traditional nylon sock.

The results serve to show that soccer footwear (socks and shoes) to affect physiological demand during soccer-specific intermittent exercise. This possibility remains, although the additional strain from the footwear was not significant ( $P > 0.05$ ) within the experimental conditions of this study. A significant effect of soccer boots may become apparent in a warmer environment. The use of other soccer equipment may also affect physiological demand during soccer-specific intermittent exercise and the aim of the next study was to determine if the use of a new temperature control foam contained within the palmar area of a goalkeeper's glove increases heat loss from the hand and reduces the demands on evaporative heat dissipation compared to a normal foam.



### **4.3 THE EFFECTS OF PHASE CONTROL MATERIALS ON HAND SKIN TEMPERATURE WITHIN GLOVES DURING SIMULATED SOCCER GOALKEEPER ACTIVITY**

#### **4.3.1 Introduction**

Soccer goalkeepers are different to outfield players in the skills they utilise, the energy requirements of their game and the clothing that they wear. The most obvious clothing difference is the use of foam padded gloves, which provide a functional and protective role. These gloves provide adequate protection against injury to the hand and also assist in gripping the soccer ball.

When items such as goalkeeping gloves are worn, heat loss by convection and evaporation is impeded due to the creation of a microenvironment close to the surface of the skin dissimilar to the ambient environment (Sullivan *et al.*, 1987; Sullivan and Mekjavic, 1992; Pascoe *et al.*, 1994a; Pascoe *et al.*, 1994b). The surface area of the hands is no longer exposed to the surrounding air and the convective exchange of heat from the body to air is virtually eliminated. Evaporative resistance of gloves at the surface of the hands is also increased, as air cannot remove the water vapour from the area of the hand. Reduced evaporation of sweat causes a build-up of moisture within the gloves and increases thermal discomfort. This may have psychological and performance ramifications (Smith *et al.*, 1997).

Phase change materials (PCMs) have been designed to change their physical state from solid to liquid to gas over a certain range of temperatures. When fabrics are coated or impregnated with PCM the thermal properties of the material can be altered to encourage heat loss or heat gain. The aim of this study was to determine if the use of a PCM fabric contained within the palmar area (extending from the wrist to the tips of the fingers) of a



goalkeeper's glove increases heat loss from the hand and reduces the demands on evaporative heat dissipation. The PCM was attached to the inner layer and was in contact with the skin. A normal foam material (NFM) of a similar thickness was used as a control material.

### 4.3.2 Research Hypotheses

Hypothesis 7: During exercise the increase in hand skin temperature when wearing gloves is significantly larger than mean skin temperature ( $\bar{T}_{sk}$ ).

Hypothesis 8: Gloves containing PCM material reduce thermal load on the hands resulting in a significantly lower hand skin temperature than NFM gloves.

Hypothesis 9: Skin blood flow following wearing PCM gloves is significantly lower than NFM gloves

Hypothesis 10: Accumulation of sweat in PCM gloves is significantly lower than in NFM gloves.

### 4.3.3 Methods

#### 4.3.3.1 Subjects

Experiments were conducted on 10 healthy, active, "non heat-acclimated" subjects (8 males and 2 females) whose characteristics are shown in Table 4.5. The participants freely volunteered for the study, which was approved by the Human Ethics Committee at Liverpool John Moores University. Written informed consent was obtained from each of the participating individuals.



**Table 4.5.** Mean (*s*) and range of subject group characteristics.

	Age (years)	Mass (kg)	Height (m)	BMI	Surface Area (m <sup>2</sup> )	Hand Length (cm)	Hand Width (cm)
Mean	26.5 ± 3.4	81.1 ± 15.8	1.75 ± 0.07	26.2 ± 3.7	1.96 ± 0.21	20.4 ± 2.0	12.1 ± 1.2
Range	20 - 32	56.5 - 114.3	1.68 - 1.88	20.0 - 32.3	1.64 - 2.39	18.1 - 25.0	9.5 - 13.3

#### 4.3.3.2 *Exercise and Environmental Conditions*

Each participant visited the laboratory on two occasions and performed 46 min and 10 s of goalkeeper specific intermittent exercise (refer to page 85) in neutral environmental conditions (approximately 21°C, 50% relative humidity). The conditions were presented to subjects in a counter-balanced arrangement. The exercise protocol employed activity patterns specific to goalkeepers and the time period was chosen to represent the average duration of half a soccer match. One session was carried out with the subjects wearing gloves with PCM inserted in the palmar region and a second session with normal foam material (NFM). The PCM was set to maintain temperature at 31°C by the manufacturers. This temperature allows for accelerated heat loss in warm environments and diminished heat loss in cold environments.




Glove Trials	
<p><b>NFM – Normal Foam Material</b></p> <p>Running shoes (subjects own)</p> <p>Socks (subjects own)</p> <p>Underwear (subjects own)</p> <p>Shorts (Umbro, 100% polyester, see Plate 4.1)</p> <p>T-Shirt (Umbro, 100% cotton, see Plate 4.1)</p> <p>NFM Gloves (Umbro, containing extra layer of normal foam material)</p>	<p><b>PCM – Phase Control Material</b></p> <p>Running shoes (subjects own)</p> <p>Socks (subjects own)</p> <p>Underwear (subjects own)</p> <p>Shorts (Umbro, 100% polyester, see Plate 4.1)</p> <p>T-Shirt (Umbro, 100% cotton, see Plate 4.1)</p> <p>PCM Gloves (Umbro, containing extra layer of phase control material)</p>
	

Plate 4.2. Details of gloves and clothing worn in the experimental trials.

The intermittent protocol was formulated using data published by Reilly and Thomas (1976) and was conducted on a non-motorised treadmill (Woodway, Seattle, WA). The protocol (Figure 3.2) represents the actions of a goalkeeper during match-play conditions and utilised four self-paced actions:- walk, jog, cruise and sprint. Both visits to the laboratory used self-paced activities.

4.3.3.3 Procedures

Subjects wore the same clothing ensemble for each session, which comprised underwear, polyester shorts, cotton T-shirt, trainers and goalkeeping gloves (Plate 4.2). The items of



clothing that belonged to the subject were worn for the first trial, washed and worn again for the second trial. Prior to testing, and upon completion, the subjects weighed themselves nude. The participant rested for 20 min during which time the thermistors were placed upon the skin with sterile surgical adhesive tape (Transpore, 3M, Michigan, USA). An additional 10 min of supine rest allowed for the measurement of skin blood flow of the thumb and forearm. The subject then stood on the treadmill and put on the gloves immediately prior to the exercise period. Immediately after the completion of the treadmill exercise, the subject removed the gloves, returned to the supine position and the measurement of skin blood flow was repeated.

#### *4.3.3.4 Measurements and Analysis*

Skin blood flow was measured using laser Doppler flowmetry (Periflux, Perimed, Järfälla, Sweden) with measurements recorded every 60 s for 10 min before exercise and for the 10 min immediately following exercise. Prior to skin blood flow being measured the subject was fitted with a short-range radio telemetry system for the measurement of heart rate (Sports Tester, Polar Electro, Kempele, Finland). Measurements were recorded at 60-s intervals during the measurement of skin blood flow, during exercise and while measuring post-exercise skin blood flow.

Mean skin temperature was measured according to the method of Ramanathan (1964), please refer to page 77. In addition hand skin temperature was measured at seven sites on the right hand and wrist: thumb, index finger, middle finger, hand palm, hand dorsal, wrist palm and wrist dorsal. Anatomical positioning is detailed in Table 3.1. Concurrently, participants were requested to give a rating of perceived exertion on Borg's original 15-point scale (Table 3.3) at 5-min intervals.

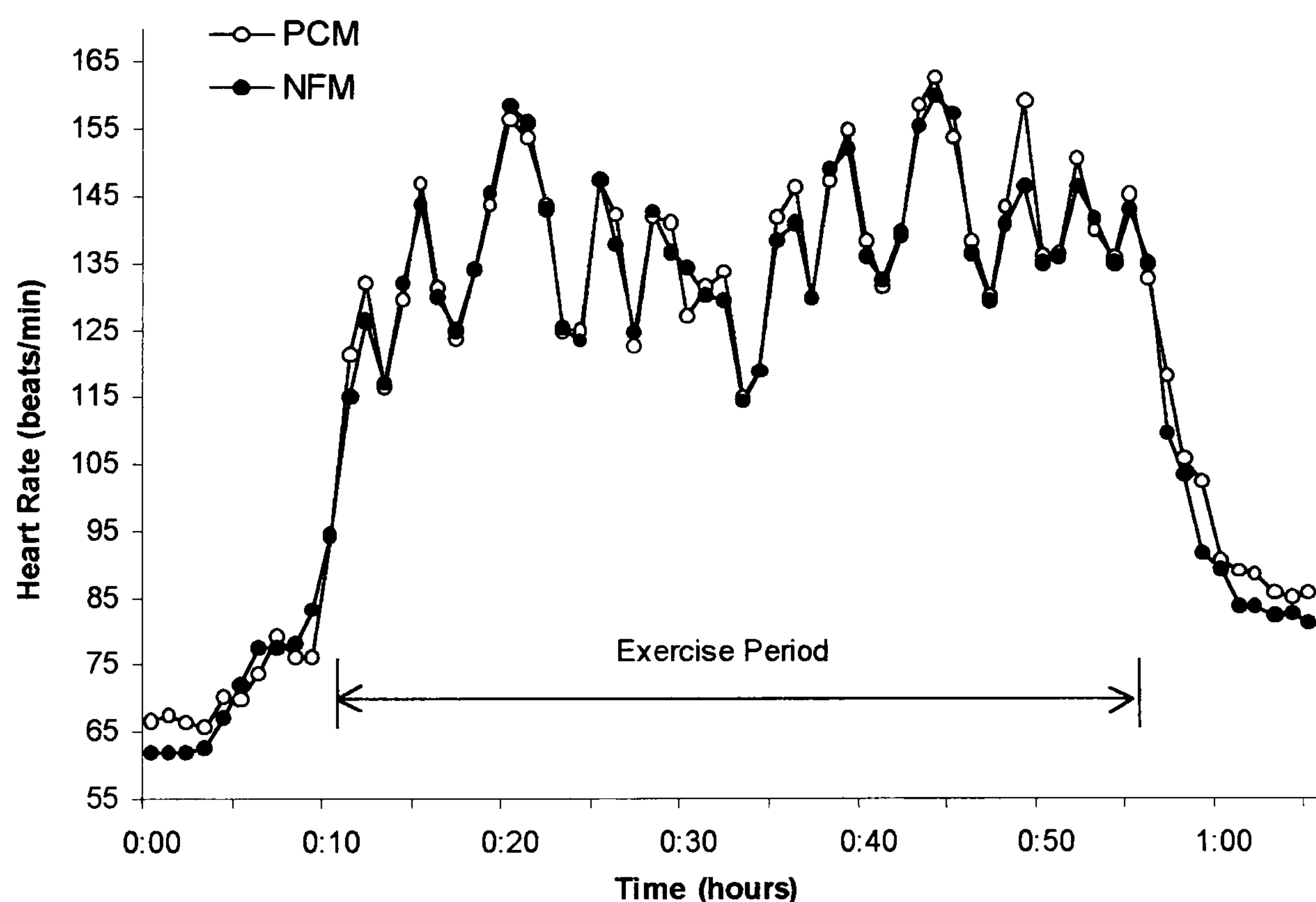


#### 4.3.3.5 Statistical Analysis

All data were analysed using descriptive statistics and Student's *t* tests. Analysis of serial measurements was also employed (Mathews *et al.*, 1990). This method uses a Student's *t* test to examine the changes within a dependent variable from baseline to end-of-test.

#### 4.3.4 Results

Figure 4.11 shows the mean heart rate for each of the two conditions. The overall mean heart rate during exercise was  $139 \pm 12$  beats  $\text{min}^{-1}$  and  $138 \pm 12$  beats  $\text{min}^{-1}$  for PCM and NFM materials respectively ( $P > 0.05$ ).



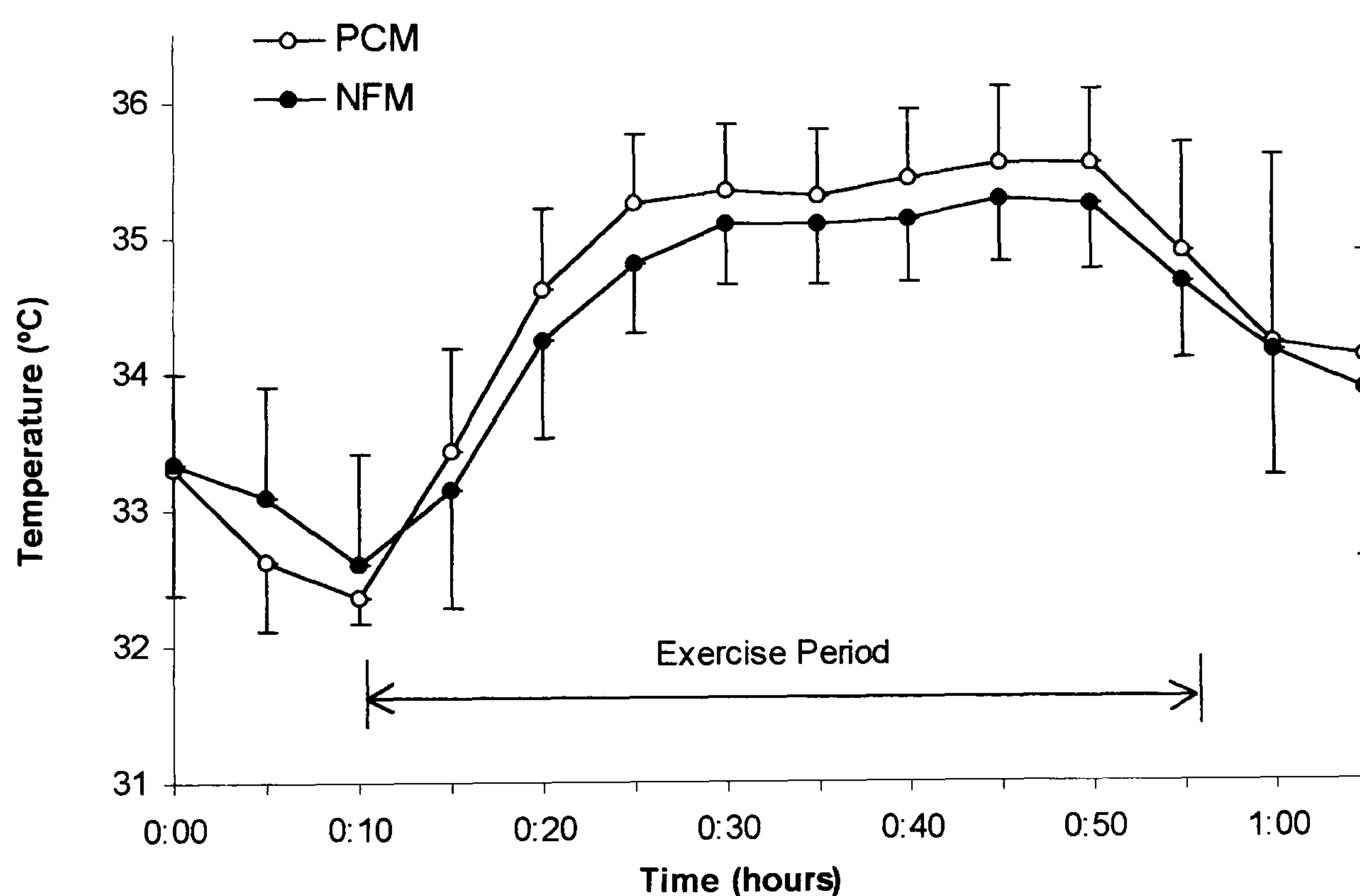
**Figure 4.11.** Mean heart rate for PCM and NFM glove materials before, during and after exercise tests ( $P > 0.05$ ).

Exercise resulted in a mean percentage body mass loss of  $0.9 \pm 0.5\%$  vs.  $0.8 \pm 0.6\%$  for PCM and NFM respectively. This corresponds to a 0.7 kg decrease in body mass in both conditions ( $P > 0.05$ ).



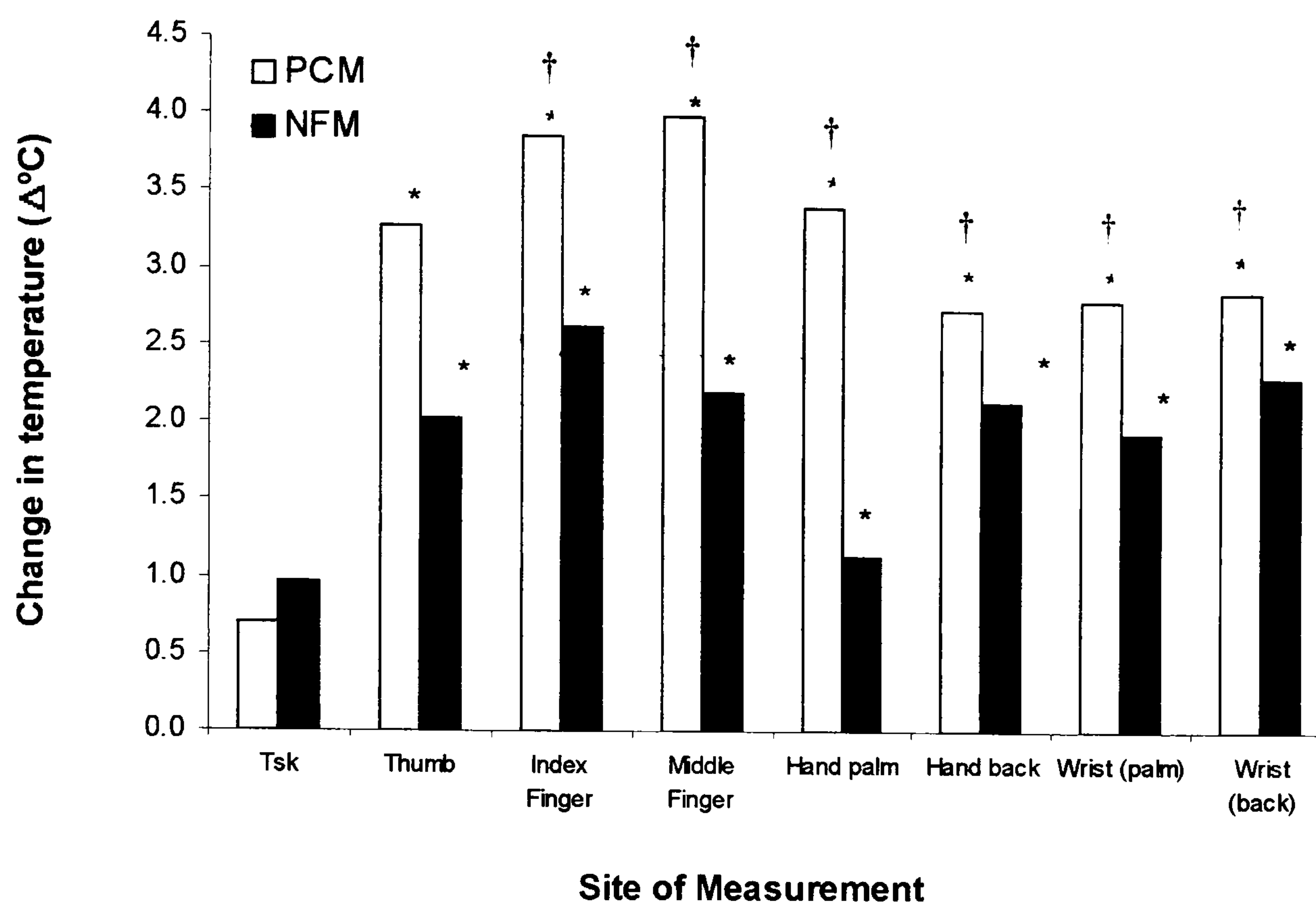
Ratings of perceived exertion were not different between conditions ( $P > 0.05$ ) at  $11.3 \pm 1.8$  for PCM and  $10.9 \pm 2.3$  for NFM. An RPE value of 11 equates to a perceived exercise intensity of 'Light'. There was a trend for the RPE to increase with exercise duration with all initial ratings lower than the ratings recorded at the end of exercise.

Figure 4.12 displays absolute skin temperature of the hand presented as a mean of all 7 sites measured and Figure 4.13 shows the change in temperature for each individual hand site. Over the duration of the exercise test the PCM glove caused a significant increase of temperature above baseline measurements in all areas of the hand ( $P < 0.05$ ) apart from the dorsal area of the hand ( $P = 0.94$ ). These differences were much more evident at the index and middle finger areas.



**Figure 4.12.** Mean ( $s$ ) changes in mean hand temperature for PCM and NFM glove materials ( $P < 0.05$ ) before, during and after exercise.





**Figure 4.13.** Mean change in temperature from baseline to end-of-exercise. \* = significant increase from baseline ( $P < 0.05$ ), † = significant difference between glove materials ( $P < 0.05$ )

**Table 4.6.** Mean ( $s$ ) absolute values and significant differences between glove materials during exercise.

Measurement	Material		<i>P</i> Value
	PCM	NFM	
Heart Rate (beats min <sup>-1</sup> )	139 ± 12	138 ± 12	0.10
<i>Temperatures (°C)</i>			
$\overline{T}_{sk}$	31.9 ± 0.3	31.8 ± 0.3	0.12
Thumb	34.9 ± 1.1	34.8 ± 0.8	0.03
Index finger	35.0 ± 1.2	34.6 ± 1.1	0.00
Middle finger	35.1 ± 1.2	34.6 ± 1.1	0.00
Hand (palmar)	35.5 ± 0.8	35.1 ± 0.5	0.00
Hand (dorsal)	34.7 ± 0.9	34.7 ± 1.1	0.94
Wrist (palmar)	35.2 ± 1.1	34.8 ± 1.0	0.00
Wrist (dorsal)	33.8 ± 1.1	33.4 ± 1.1	0.00
Mean hand	34.9 ± 1.0	34.6 ± 0.9	0.00

Table 4.6 shows mean absolute values for heart rate and absolute temperatures during exercise. There was no significant difference between conditions for mean skin

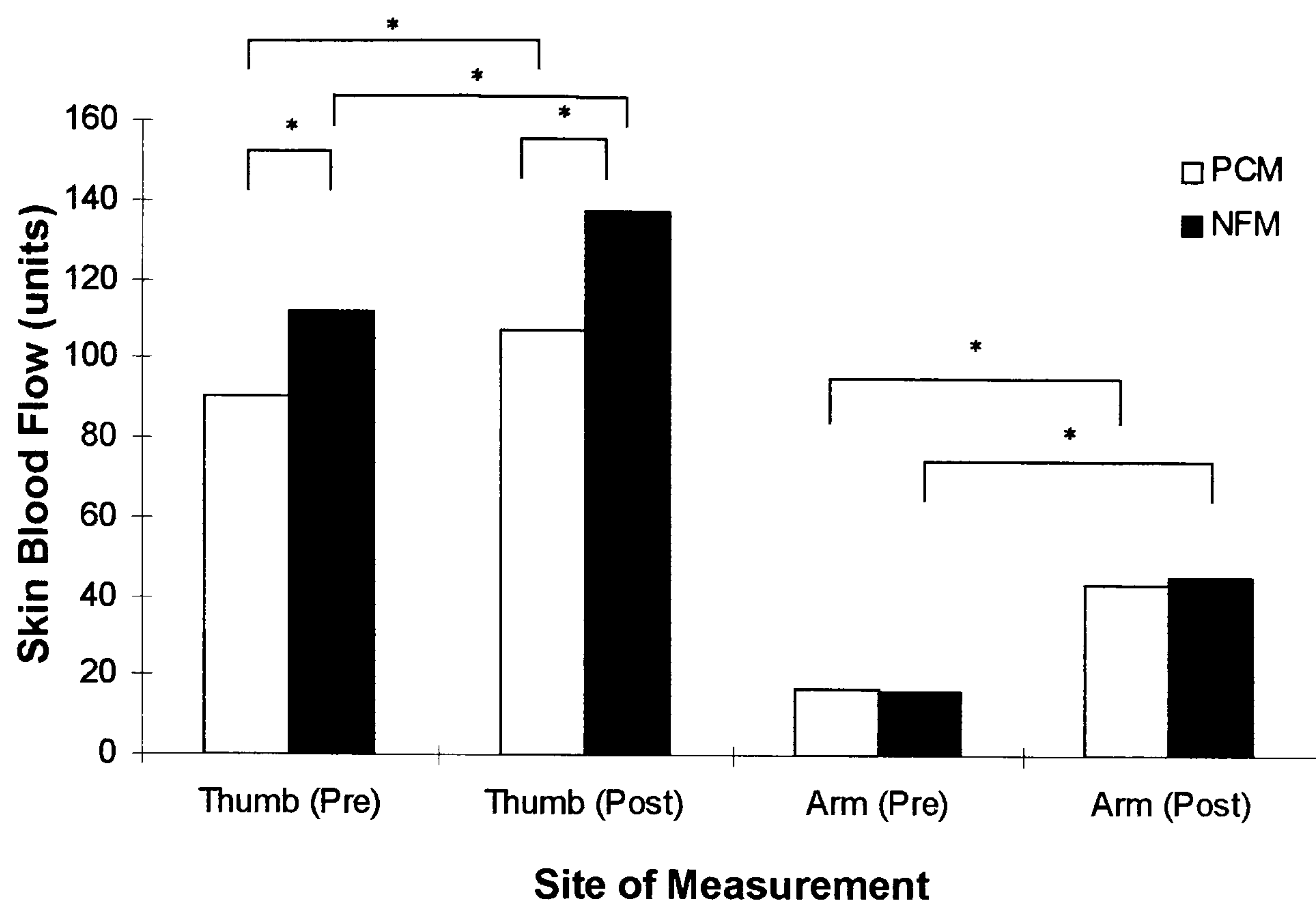


temperature or heart rate. The PCM material exhibited higher overall absolute mean skin temperatures for all hand skin sites with only the dorsal area of the hand not showing a significant difference above the NFM condition ( $P = 0.94$ ) (Table 4.6).

Gloves were weighed immediately before and after each exercise test session to determine moisture uptake. There was a significantly greater sweat retention in PCM gloves ( $P < 0.05$ ) compared to NFM gloves,  $10.5 \pm 2.2\%$  vs.  $8.2 \pm 2.7\%$  for the left glove and  $10.7 \pm 2.5\%$  vs.  $8.9 \pm 2.8\%$  for the right glove.

Forearm and thumb skin blood flow increased post-exercise ( $P < 0.05$ ) for both glove materials (Figure 4.14). Post-exercise thumb skin blood flow was significantly higher for the NFM glove than the PCM glove ( $P < 0.05$ ). Skin blood flow for two subjects data were removed for analysis as these subjects exhibited unusual responses with highly attenuated skin blood flow, which skewed the data. This response was thought to have occurred due the sensors being taped too tightly to the thumb. Post-exercise forearm skin blood flow was significantly higher compared to pre-exercise for both conditions but there was no significant difference between glove types.





**Figure 4.14.** Changes in thumb and forearm skin blood flow for PCM and NFM glove materials, pre-test and post-test. (\* =  $P < 0.05$ )

#### 4.3.5 Discussion

Similarity in mean heart rate between experimental conditions indicated that the same intensity level was maintained for both glove treatments. The close matching of the two heart rate recordings confirms that all subjects strictly adhered to the protocol of treadmill actions. The protocol incorporated many rapid changes in speed lasting a median of 5 s, therefore strict reproduction of the changes in speed were necessary. The parity of the workload is also confirmed by the similarity of perceived exertion ratings ( $P < 0.05$ ). The mean RPE values illustrate the overall intensity of the exercise protocol.

The protocol was intended to simulate the activity profile of a soccer goalkeeper as closely as possible on a treadmill. Although the most realistic testing of soccer activity is during a competitive match, this situation does not allow for detailed physiological assessment, control of environment or the accurate repetition of experimental trials.



As the changes in nude body weight did not differ ( $P > 0.05$ ) between conditions the overall sweat losses due to environmental and exercise thermal load were similar in the two trials. The mean loss of body mass of  $0.9 \pm 0.5\%$  and  $0.8 \pm 0.6\%$  for PCM and NFM due to sweat production reflects the lower intensity of goalkeepers compared with outfield players (Reilly and Thomas, 1976). Nevertheless, even mild dehydration can diminish performance (Maughan, 1993; MacLaren, 1996).

Whole-body mean skin temperature was not differ between conditions ( $P > 0.05$ ). In contrast, analysis of serial measurements indicated that, apart from the dorsal hand ( $P = 0.94$ ), all sites of measurement on the hand and wrist were significantly higher when wearing the glove containing PCM. Immediately on wearing the gloves there was a sharp increase in skin temperature, which was more pronounced in the glove containing PCM. These findings are in contrast to research published by Branson *et al.* (1988) who reported skin temperature, perceived temperature and perceived thermal discomfort all increased similarly during exercise irrelevant of the glove material worn. The PCM material in this study was designed to absorb heat from the skin in order to maintain a steady and comfortable temperature at  $31 \pm 1^\circ\text{C}$ . The present data do not support these claims and, moreover, suggest that the material's performance is significantly inferior to that of a material used routinely in goalkeeping gloves.

The increase in mass due to sweat production and absorption was higher for the PCM glove than that seen in the glove containing NFM. The overall change in mass was  $10.55\% \pm 2.4$  and  $8.5\% \pm 2.8$  for the PCM and NFM materials, respectively. The gain in mass was slightly higher in the right glove for both conditions and this may have been due to the presence of the thermistors (only in the right hand glove) causing a greater thermal load.



The properties of clothing which affect heat exchange are thermal insulation (affecting air velocity) and evaporative resistance (Holmér, 1995). Skin temperature has been shown to be significantly reduced in conditions of high air movement compared to lower air movement (Adams *et al.*, 1992; Bouskill *et al.*, 1998a). Elevated air velocity increases convective and evaporative heat loss and improves heat dissipation from the skin. If the PCM material was predisposed to sticking to the surface of the skin when damp with sweat, the small amount of air movement within the enclosed micro-environment of the glove would be further reduced or eliminated. Sweat would be absorbed directly from the skin into the foam resulting in an increased sweat accumulation in the glove and increased skin temperature due to ineffectual evaporative cooling. This process results in production of extra sweat in an attempt to cool the skin (Nielsen and Endrusick, 1992), further exacerbating the problem of heat loss within the gloves. These effects are seen in the results described above.

The build-up of condensation within the clothing layer is an important factor in heat strain (Lotens *et al.*, 1995). During exercise there is significant production of sweat and the accumulation of sweat seen in the gloves examined here is highly relevant in causing an increase in skin temperature. If the trapped moisture in the gloves was allowed to evaporate, a contribution to heat transfer would be made, but this is not evident in the gloves examined here. As sweat is trapped within the glove and does not evaporate, heat loss into the surrounding environment is restricted, thereby causing an elevation in hand skin temperature.

Arm skin blood flow increased similarly following exercise in both conditions. This response is expected during recovery in order to dissipate the exercise-induced thermal load. The measurements of post-exercise blood flow of the thumb showed a significant



difference between the two materials where the skin blood flow was higher in the NFM condition ( $P < 0.05$ ). Although both conditions produced an increase in skin blood flow, wearing the NFM glove appeared to elevate blood flow above the increase observed when wearing PCM. This may suggest that the PCM glove attenuates skin blood flow, however, skin temperature is elevated compared to the NFM glove and it is difficult to explain why this may occur. It may be that during measurement the increased sweat production when wearing the PCM glove necessitated tighter application of surgical tape to ensure the skin blood flow laser sensor was properly attached during post exercise measurement. This would cause an artificially reduced post-exercise skin blood flow in the thumb.

#### **4.3.6 Conclusion**

Further material development is necessary to address the problems of moisture build-up and heat gain within the microenvironment of the glove. The particular specification of PCM evaluated encourages heat gain rather than heat loss and is therefore inappropriate to enhance thermal comfort in this setting.



#### 4.4 CHAPTER SYNTHESIS

The overall conclusion resulting from the work presented in this chapter is that the periphery responds to thermal stress in a different manner to the rest of the body.

The experimental work contained in this chapter has fulfilled Aim 1 set out on page 3. The demands of soccer type exercise on foot skin temperature were established in the laboratory. The results of the investigation then raised the questions of what thermal stresses were caused at the foot from soccer footwear, and the demands of goalkeeping gloves during simulated goalkeeper activity. These three experimental studies served to quantify the effects of exercise on thermal responses of the hands and feet when wearing soccer equipment materials.

Soccer footwear does not have a significantly detrimental effect on performance compared with training shoes ( $P > 0.05$ ). However, there was some evidence of an increased thermal and physiological strain, with heart rate and core temperature elevated ( $P > 0.05$ ) when wearing boots compared to trainers and boots with *Metcradle* insoles. Skin temperature of the foot was found to be slightly elevated ( $P > 0.05$ ) on the foot wearing the *Comformax* sock compared to the traditional sock.

The evaluation of two types of foam material in goalkeepers' gloves resulted in some significant findings. Localised hand skin temperature, sweat production, and skin blood flow post-exercise were elevated ( $P < 0.05$ ) when wearing the PCM glove compared to the NFM glove.

The result of the experimental work demonstrated that soccer footwear (socks and shoes) and goalkeeping gloves may have ramifications for physiological demand during outfielder and goalkeeper specific intermittent exercise, respectively. The slight thermal



demands caused by soccer equipment being worn on the periphery may, in a hot environment especially, cause significantly increased thermal demands, elevating core temperature and risking an earlier time to fatigue.



## CHAPTER 5. EFFECTS OF CLOTHING ON WHOLE-BODY THERMOREGULATION



## 5. EFFECTS OF CLOTHING ON WHOLE-BODY THERMOREGULATION

*This chapter constitutes the first of three studies examining whole-body thermoregulation. The effects of clothing layers are examined during soccer specific intermittent exercise in a neutral environment. The clothing under examination is also specific to soccer.*

### 5.1 INTRODUCTION

The wearing of clothing alters the interface between the human and the surrounding environment. Clothing acts as a barrier to heat loss in resisting both dry heat exchange and evaporative heat exchange (Havenith, 1995) altering the climate to which the skin is exposed by creating a microenvironment between the clothing and skin (Sullivan and Mekjavic, 1992). The resistance to evaporative and convective heat loss may be increased imposing additional heat stress and demands upon the thermoregulatory system. During exercise in hot and humid environments, core temperature is elevated which may reduce the ability to perform an activity. The same stresses can be imposed through limitations on sweat evaporation (Kenney *et al.*, 1993).

Military protective clothing has been shown to increase the metabolic cost of performing tasks by adding weight and restricting movement (Nunneley, 1989). Increases in oxygen consumption have been calculated at 10%. Soccer training clothing is much lower in weight and much less restrictive than the ensembles used in military protection. The clothing may still influence the physiological and thermal demand of the activity by changing the microenvironment. Therefore it will be useful to establish the added impact on a soccer player when wearing training clothing as the effects on overall performance may have implications for match-play performance.



When a clothing ensemble consists of more than one layer, the properties of air trapped between clothing layers becomes significant (Havenith, 1999). The air trapped between clothing items is still up to 6 mm from the clothing surface with air outside of this layer moving due to temperature gradients. When soccer players wear a training T-shirt and training top, air is trapped within the two layers increasing the insulation of the garments. When an individual is moving and air is moving due to wind, the trapped air between clothing layers will not be as thick and hence insulation is reduced compared to a still, sheltered individual. The effect of the training clothing ensemble on thermal conditions is not known and this study attempts to quantify this.

### **5.1.1 Research Hypotheses**

Hypothesis 11: Wearing a waterproof, impermeable soccer training top during soccer specific intermittent exercise increases thermoregulatory demand.

Therefore it is hypothesised that:

- a. Core temperature is greater when wearing a soccer training top compared to the same clothing ensemble without the training top.
- b. Skin temperature is greater when wearing soccer training top compared to the same clothing ensemble without the training top.
- c. Thermal perception is greater when wearing a soccer training top compared to the same clothing ensemble without the training top.

Hypothesis 12: Wearing a waterproof, impermeable soccer-training top during soccer specific intermittent exercise increases physiological demand.

Therefore it is hypothesised that:

- a. Heart rate is greater when wearing a soccer training top compared to the same clothing ensemble without the training top.



- b. Rating of perceived exertion is greater when wearing a soccer training top compared to the same clothing ensemble without the training top.

Hypothesis 13: Wearing a waterproof, impermeable soccer training top during soccer specific intermittent exercise increases metabolic demand. Therefore it is hypothesised that:

- a. Blood lactate is greater when wearing a soccer training top compared to the same clothing ensemble without the training top.
- b. Blood glucose is greater when wearing a soccer training top compared to the same clothing ensemble without the training top.

## 5.2 METHODOLOGY

### 5.2.1 Subjects

Eight healthy male university students participated in this study. The physical characteristics of the subjects are presented in Table 5.1. All subjects were moderately active and participated in soccer training a minimum of once a week and were considered to be non-acclimatised to any environmental extremes. Written information concerning the nature, purpose, practical details, risks and procedures of the study were given to all participants and all freely volunteered for the study with written informed consent obtained from each of the individuals. The study was approved by the Human Ethics Committee at Liverpool John Moores University and conforms to all policy regarding the use of human subjects.

**Table 5.1.** Mean (*s*) and range characteristics of subject group.

	Age (years)	Mass (kg)	BMI	Surface Area (m <sup>2</sup> )
Mean	25 ± 6	79.3 ± 10.3	26.7 ± 2.3	1.96 ± 0.06
Range	20 - 37	67 - 99	20.7 - 28.1	1.77 - 2.25



5.2.2 Protocol and Procedures

Each participant visited the laboratory on two separate occasions, at least three days apart and tests were conducted at the same time of day to eliminate any circadian variation in performance or thermoregulatory response. Each subject was asked to perform 45 min of intermittent exercise in one of two clothing ensembles:



Clothing Trials	
<div>Ensemble A</div> <div>Running shoes (subjects own), Socks (Umbro <i>Comformax</i>), Underwear (subjects own), Shorts (Umbro, 100% polyester), T-Shirt (Umbro, 100% polyester)</div> <div></div>	<div>Ensemble B</div> <div>Running shoes (subjects own), Socks (Umbro <i>Comformax</i>), Underwear (subjects own), Shorts (Umbro, 100% polyester), T-Shirt (Umbro, 100% polyester), Waterproof Training Top (100% Polyurethane lined with 100% Nylon)</div> <div></div>

Plate 5.1. Clothing and equipment worn in the experimental work.

The clothing is of the type worn by soccer players during training and clothing treatments were administed to subjects using a counter-balanced design.



The exercise protocol employed intermittent activity patterns specific to outfield soccer players and was conducted on a programmable motorised treadmill (HP Cosmos, Nussforf-Traunstein, Germany) and is illustrated in Figure 3.3. All subjects were familiarised with the equipment used and had previously run on a motorised treadmill.

### 5.2.3 Measurements and Analysis

Heart rate, rectal temperature, mean skin temperature ( $\bar{T}_{sk}$ ) and mean body temperature ( $\bar{T}_b$ ) and environmental temperature were assessed throughout the exercise period as detailed in Chapter 3 (page 77).

Arterialised capillary blood samples were taken on four occasions: pre-test, mid-test, immediately post-test and 5 minutes post-test. Duplicate 50  $\mu$ l samples of arterialised capillary blood were immediately deproteinized in 100  $\mu$ l of 8% perchloric acid, centrifuged, supernatant removed, placed into fresh tubes, frozen and then later analysed for lactate and glucose.

During the period of exercise participants were requested to give a ratings of perceived exertion on a the Borg (1970) modified scale (Table 3.2) and additionally ratings of thermal comfort (Nielsen *et al.*, 1989) as shown in Table 5.2.



**Table 5.2.** Nielsen (1989) scale of thermal comfort.

Rating	Description
1	very cold
2	cold
3	cool
4	slightly cool
5	neutral
6	slightly warm
7	warm
8	hot
9	very hot

### 5.3 RESULTS

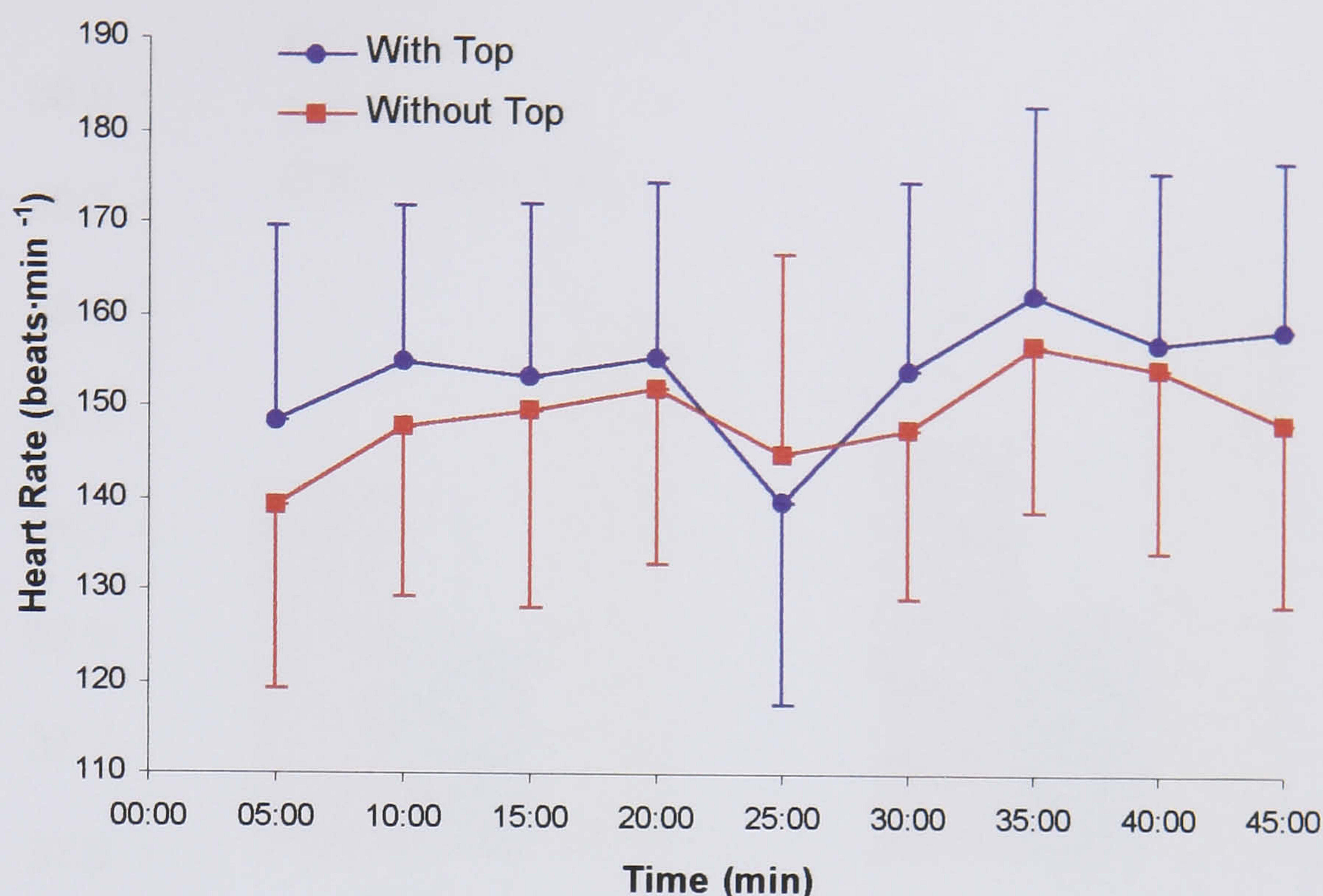
#### 5.3.1 Environmental Conditions

The ambient temperature was stable during all trials. Mean air temperature in the laboratory during the trials with the training top was  $17.9 \pm 0.2^{\circ}\text{C}$  and in the trials without the training top the mean air temperature was  $18.0 \pm 0.2^{\circ}\text{C}$ . A repeated-measures ANOVA was carried out and there were no differences between trials ( $F_{1,7} = 0.474$ ,  $P = 0.513$ ) or over the duration of the exercise ( $F_{8,56} = 3.073$ ,  $P = 0.076$ ).

#### 5.3.2 Cardiovascular Responses

Figure 5.1 shows the mean heart rate during exercise when wearing the two clothing ensembles. The overall mean heart rate during exercise was  $154 \pm 8$  beats  $\text{min}^{-1}$  when wearing a training top and  $149 \pm 8$  beats  $\text{min}^{-1}$  without the training top.





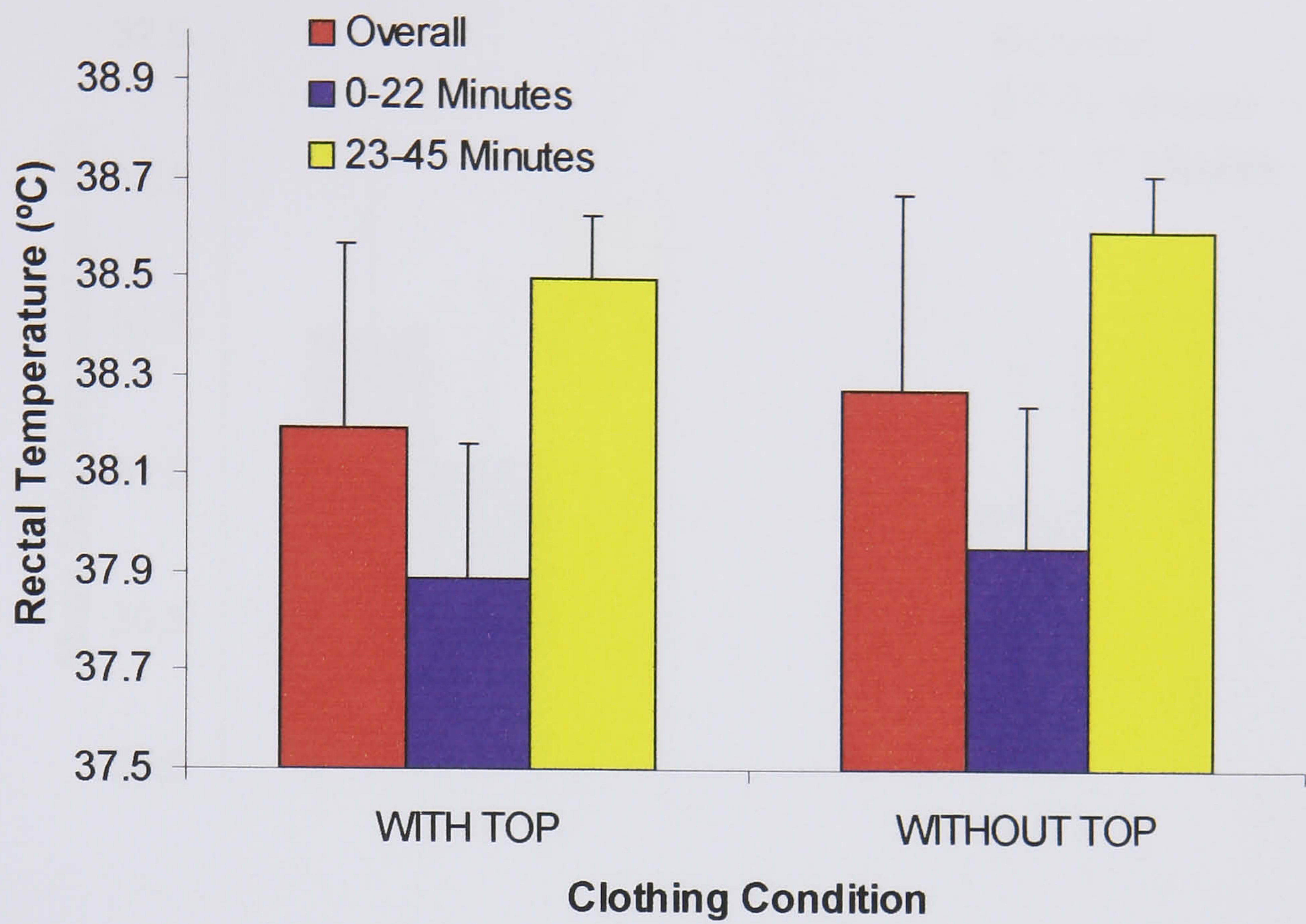
**Figure 5.1.** Mean (*s*) heart rates during soccer-specific exercise with and without the training top.

The slight differences found between clothing treatments were not statistically significant ( $F_{1,7} = 0.575$ ,  $P = 0.473$ ). A difference ( $F_{5.583, 39.081} = 6.102$ ,  $P = 0.000$ ) was found over time and in both treatments the mean heart rate was greater in the second half of the protocol compared to the first half ( $F_{1,7} = 15.268$ ,  $P = 0.006$ ). There was no interaction between main effects ( $F_{9,63} = 1.257$ ,  $P = 0.309$ ).

### 5.3.3 Thermoregulatory Responses

No difference was observed in resting rectal temperature before the trials ( $F_{1,7} = 1.088$ ,  $P = 0.331$ ). Rectal temperature (Figure 5.2) was influenced by the duration of exercise ( $F_{1.177, 8.237} = 5.649$ ,  $P = 0.040$ ) but not the clothing ensemble ( $F_{1,7} = 0.036$ ,  $P = 0.855$ ).



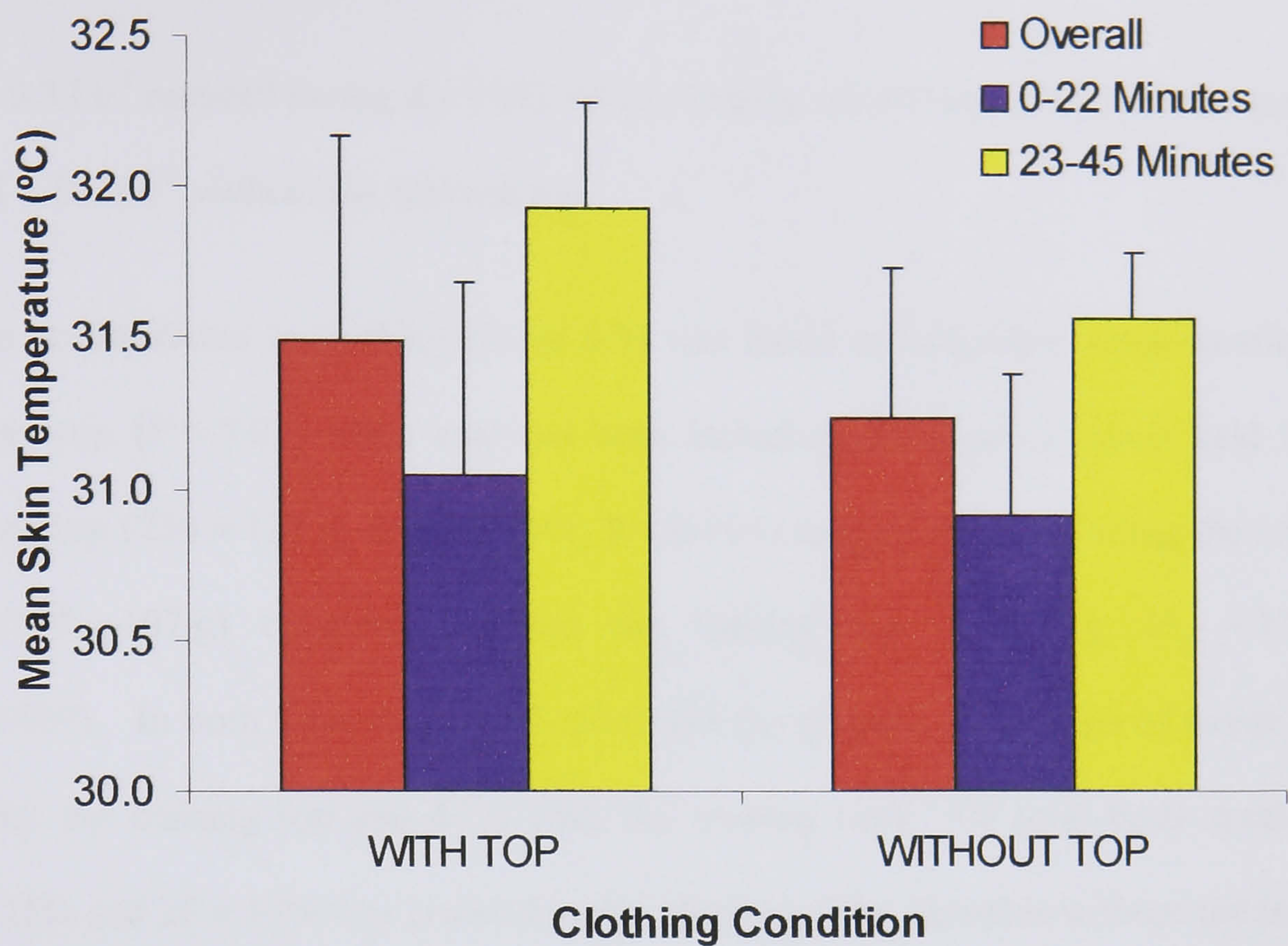


**Figure 5.2.** Mean (*s*) rectal temperature during soccer-specific exercise when wearing a soccer training ensemble with or without a shower jacket.

Mean core temperature when wearing the training top was consistently higher by 0.1°C over both the overall 45 min of exercise and if 0 – 22 min and 23 – 45 min periods are considered separately. Core temperature during the second half of the exercise was higher than the first half ( $P < 0.01$ ) in both clothing treatments.

Weighted skin temperature (Figure 5.3) was not different ( $F_{1,7} = 1.388, P = 0.277$ ) between clothing trials and was not significantly influenced by time ( $F_{1,074, 7.516} = 1.676, P = 0.236$ ). However, as shown in Figure 5.3, the mean skin temperature when wearing a training top was fractionally higher than without, both overall and when means were reported over the two halves of the protocol.





**Figure 5.3.** Weighted mean skin temperature during soccer-specific exercise in both clothing ensembles.

Mean body temperature ( $\bar{T}_b$ ) showed no differences ( $F_{1,7} = 0.097$ ,  $P = 0.765$ ) between clothing conditions with mean temperature over the whole duration of the exercise at exactly  $36.9 \pm 0.4^\circ\text{C}$  both with a training top and without a training top. Almost identical mean temperatures also resulted when the exercise was split into 0 – 22 min ( $36.5 \pm 0.3^\circ\text{C}$  and  $36.6 \pm 0.4^\circ\text{C}$  with and without a training top respectively) and 23 - 45 min ( $37.2 \pm 0.1^\circ\text{C}$  and  $37.2 \pm 0.1^\circ\text{C}$  with and without a training top respectively) periods. No effect of time ( $F_{1,285,8.993} = 2.991$ ,  $P = 0.113$ ) or clothing  $\times$  time interaction ( $F_{1,470,10.287} = 1.228$ ,  $P = 0.317$ ) was observed.

Mean sweat rate was calculated assuming that secretion was consistent throughout the exercise duration and respiratory vapour loss negligible. Sweat rates between clothing conditions were found not to be different ( $F_{1,7} = 0.428$ ,  $P = 0.534$ ). A mean sweat rate of



$1.2 \pm 0.3 \text{ l h}^{-1}$  resulted during the trial with the training top compared to a mean sweat rate of  $1.1 \pm 0.6 \text{ l h}^{-1}$  without the training top.

Sweat accumulation in clothing (Table 5.3) was found to be greater when wearing the training top ( $P < 0.01$ ) when analysed both including the mass of sweat held in the training top ( $234 \pm 127 \text{ g}$ ;  $F_{1,7} = 17.841$ ,  $P = 0.004$ ) and when not including the training top ( $185 \pm 107 \text{ g}$ ) compared without the training top ( $68 \pm 52 \text{ g}$ ;  $F_{1,7} = 13.070$ ,  $P = 0.009$ ). In both ensembles the T-shirt held the greatest percentage of sweat (65% without the training top and 67% with the training top). Of total body mass loss,  $20 \pm 25\%$  and  $28 \pm 17\%$  was retained in the clothing of the ensemble without the training top and the ensemble with the training top, respectively.

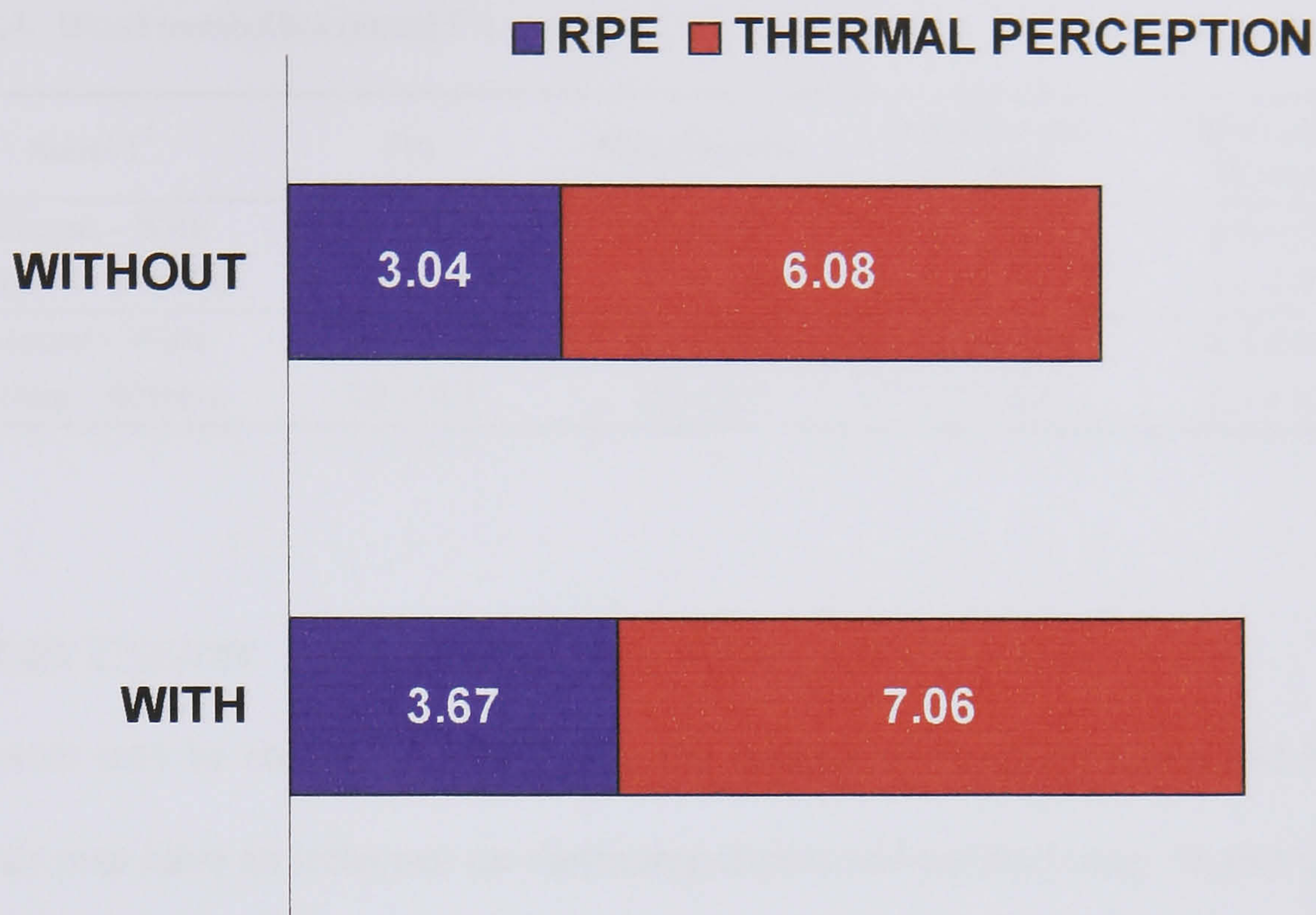
**Table 5.3.** Mean (*s*) sweat retention in garments (% of total and absolute amount retained).

	Training top		T-shirt		Shorts		Socks	
	%	g	%	g	%	g	%	g
<i>With training top</i>								
Mean	21.8	48.9	67.0	150.9	8.7	28.3	2.5	5.8
<i>s</i>	4.5	24.7	6.9	67.1	7.2	37.7	1.1	3.8
<i>Without training top</i>								
Mean	-	-	65.1	52.6	16.5	8.4	18.4	7.4
<i>s</i>	-	-	23.2	47.4	9.6	5.0	18.4	3.7

### 5.3.4 Psychophysical Ratings

In Figure 5.4 the rating of perceived exertion and rating of thermal comfort are displayed together. The overall means are annotated on the figure and show that there is a higher perceived exertion ( $F_{1,7} = 8.607$ ,  $P = 0.022$ ) and thermal stress ( $F_{1,7} = 6.112$ ,  $P = 0.043$ ) when wearing the training top compared to the same clothing ensemble without the training top.





**Figure 5.4.** Ratings of perceived exertion (RPE) and thermal perception during soccer-specific intermittent exercise.

### 5.3.5 Metabolic Responses

The blood glucose concentration (Table 5.4) was not different ( $F_{1,7} = 4.915, P = 0.062$ ) between the two clothing treatments at any time point, but was slightly elevated during the training top condition. Concentrations of blood glucose did not change over the duration of the exercise ( $F_{3,21} = 1.883, P = 0.163$ ).

The blood lactate concentration (Table 5.4) was not different between clothing trials ( $F_{1,7} = 1.971, P = 0.203$ ) but increased above resting levels in both conditions ( $F_{3,21} = 8.044, P = 0.017$ ) mid-exercise and immediately post-exercise. Students t-tests showed lactate concentrations 5 min post-exercise to be at resting levels for both conditions ( $P > 0.05$ ).



**Table 5.4.** Blood metabolites (mmol l<sup>-1</sup>).

mmol l <sup>-1</sup>	Pre	Mid-Exercise	Post-Exercise (0 min)	Post-Exercise (5 min)
Glucose - With	3.5 ± 1.0	3.4 ± 0.9	3.4 ± 0.7	3.6 ± 1.0
Glucose - Without	3.3 ± 1.0	3.0 ± 0.6	3.1 ± 0.6	3.4 ± 0.7
Lactate - With	1.2 ± 0.4	2.8 ± 1.8	2.5 ± 1.7	1.5 ± 0.7
Lactate - Without	1.0 ± 0.3	2.5 ± 1.7	2.1 ± 1.3	1.3 ± 0.7

#### 5.4 DISCUSSION

Sportswear may be considered a barrier in the context of thermodynamics and therefore garments may have an influence on thermoregulation and performance. In this study the effect of wearing a waterproof impermeable soccer-training top in addition to T-shirt and shorts was investigated during simulated soccer-specific intermittent exercise on a motorised treadmill. The training top caused no appreciable differences in any of the physiological variables compared to the same clothing ensemble without the training top.

Although there were no statistically significant differences in any of the variables measured, there were some slight differences observed. Heart rate (Figure 5.1) was a mean of 5 beats min<sup>-1</sup> higher when wearing the training top ( $P > 0.05$ ) suggesting a greater physiological load imposed by the extra clothing layer. The mean heart rates observed correspond to previous recordings during soccer match-play (Bangsbo, 1994a; Reilly, 1996c) but were lower than others (Van Gool *et al.*, 1988; Drust, 1997). Physiological demands of running without a ball are lower than running with a ball (Reilly and Ball, 1984) while the energy requirements of running backwards and sideways are higher than running forwards (Reilly and Bowen, 1984), which may account for the slightly lower heart rates when running on a treadmill.



Overall mean skin temperature was also slightly elevated when wearing the training top ( $31.5 \pm 0.7$  °C) compared to the same ensemble without the training top ( $31.2 \pm 0.05$  °C). Similarly mean rectal temperature was higher when wearing the training top, although not significantly ( $P > 0.05$ ). The lack of significant differences between clothing ensembles is surprising considering that multiple clothing layers increase the insulation of a garment due to increased volume of trapped air (Havenith, 1999). Impermeable fabrics have been shown to reduce the vapour transfer properties of a garment (Parsons *et al.*, 1999) and hence restrict sweating and elevate body temperature. Nonetheless, it has been reported that the thermal responses of an individual do not necessarily reflect the insulation properties of the clothing worn (Jette *et al.*, 1995) and very small differences have been observed in core temperature when athletic and protective clothing were compared.

The training top was the same size for all subjects and was loosely fitting on most of the participants. The only exception was subject 6 on whom the top was more closely fitting although still not tight or restrictive. Movement of air between the clothing layers may have been sufficient to reduced the thermal insulation and evaporative resistance due to an effect known as 'pumping' or 'bellows' (Bouskill *et al.*, 1998a) caused by movement. The effect increases the internal ventilation of the clothing microenvironment (Vogt *et al.*, 1983) while moisture and heat transfer through the clothing layer is unaffected (Kakitsuba *et al.*, 1988). However, Lotens (1987) showed theoretically that during moderate exercise the ventilation of a garment must reach  $450 \text{ l min}^{-1}$  to prevent condensation of vapour within a rainproof layer. Lotens and Havenith (1988) later found using trace gas methods that even under optimal conditions, a ventilation of  $360 \text{ l min}^{-1}$  was the highest rate possible for a rainwear ensemble (Lotens and Havenith, 1988). Therefore, greater sweat accumulation occurs beneath the rainproof training top, this is reflected by a three-fold



increase in sweat accumulation in the T-shirt when wearing the training top. Additionally the fibre type of a fabric has been shown not to be relevant for thermal comfort when the garment is loose fitting (Markee *et al.*, 1991) allowing air to circulate near to the skin. The vapour permeability of a tight sports garment greatly affects the sweat retention and thermoregulatory responses (Brownlie *et al.*, 1987). These factors may explain the lack of differences in thermoregulatory responses during exercise when wearing an impermeable training top.

Insulation of a clothing layer is proportional to its thickness and this is relatively independent of fibre type (Lotens and Havenith, 1991). However, air of the same thickness is more insulative than fabric due to radiative heat transfer and conductance of heat through fabric fibres.

Mean sweat rate during exercise was not different between clothing conditions ( $P > 0.05$ ) although there was a slightly higher rate of sweating when wearing the training top of an extra  $100 \text{ ml h}^{-1}$ . More sweat accumulated in the clothing ensemble that included the jacket ( $P < 0.05$ ) although total sweat production was not different ( $P > 0.05$ ). The increased accumulation of sweat within the ensemble including the training top is to be expected considering the impermeable fabric and resistance to vapour transfer. The sweat is retained in the clothing without being evaporated into the surrounding environment, concomitantly losing the benefits of heat loss through evaporation and decreasing thermal comfort. As already observed, the differences in thermoregulatory and physiological responses are so slight as to be non-significant ( $P > 0.05$ ). However, a small effect of the training top does appear to be present and the effects of such a garment in a hotter and more humid environment should be considered.



The perception of environmental temperature was assessed through the use of a thermal perception ballot (Nielsen *et al.*, 1989). Humidity cannot be sensed through the skin but skin wettedness can be perceived impacting upon thermal comfort while the garments worn also affect thermal perception (Gwosdow *et al.*, 1986; Nielsen and Endrusick, 1990). Again there were no significant differences ( $P > 0.05$ ) between clothing ensembles, but there were small differences evident in the overall mean values obtained. During exercise the perception values equate to approximately 'somewhat hard' and 'warm' when wearing the training top and 'moderate' and 'slightly-warm' without the training top for perceived exertion and thermal comfort, respectively.

Lotens *et al.* (1995) compared impermeable and semi-permeable clothing ensembles and showed that the thermal stress of both ensembles was similar while mechanisms of heat transfer were observed to be somewhat different. When wearing the impermeable training top, the majority of heat dissipation was via the mechanisms of dry heat loss and the heat of condensation as the impermeable fabric is a barrier for the usual route of sweat evaporation. In this study, increased heat loss by means of condensation on the inner layer of the rain jacket was suggested by a slightly higher sweat accumulation when wearing the rain jacket. In contrast, heat loss when wearing a semi-permeable garment is mainly through evaporation of sweat and vapour transfer through the fabric into the surrounding environment.

The lack of thermal strain produced by the training top may be due to the item being placed over another clothing layer. The impact on insulation of the clothing ensemble would not be as great as if the extra garment was placed over an area not previously covered (McCullough, 1993). Insulation due to trapped air may be minimal due to



physical movement of the subject during activity allowing air to move into the garment through the open neck, cuffs and waistband (McCullough *et al.*, 1983) and altering the heat exchange with the surrounding environment. The clothing ensemble without the training top consists of a short-sleeved T-shirt and shorts while the added training top is a long-sleeved garment. The somewhat elevated ( $P > 0.05$ ) heart rate, core temperature, skin temperature, rating of perceived exertion and thermal perception when wearing the training top may be due to the lower arms being covered in that treatment. The localisation of heat transfer has been observed within the clothing microenvironment (Nielsen and Endrusick, 1992) and is dependent upon several factors including; body movements, garment design and fit, air movement and direction, sweating and evaporation of sweat. Therefore, heat exchange is dependent upon many factors and particular areas of the body allowing one region to compensate for another.

During high intensity bouts of activity, such as maximal sprints during soccer match-play, the stores of glycogen within the muscle are used before plasma glucose. The glucose released from the liver then remains in the circulation, thereby elevating the blood glucose concentration. Following a sprint the levels of blood glucose will decrease as the muscle replenishes the depleted glycogen stores. During prolonged steady state exercise the rate of glycogenolysis is sufficient to supply the requirements of the muscle directly and plasma glucose levels are only slightly increased above resting levels. In this study the glucose levels (Table 5.4) did not increase above resting levels ( $P > 0.05$ ) indicating that the rate of glycogenolysis is supplying the muscle requirements more directly and the high intensity bouts of activity are compensated for during the low activity bouts and static pauses.



When glycogen and glucose are used for energy provision the by-product of the process is called lactic acid or lactate. During sprints the demand on the glycolytic production of energy are high and levels of lactate increase. The energy requirement for sprinting activity is provided by anaerobic glycolysis and hence there is a requirement for good anaerobic exercise capacity. The elevation of lactate in the muscle limits the further breakdown of glycogen, hence limiting energy provision and contributing to fatigue. Lactate concentration in the muscle is difficult to determine and therefore concentrations of lactate in the blood are measured. The concentration of lactate within the circulation is not as great as the concentration within the active muscle. Nevertheless, it does allow a proportional comparison. Blood lactate concentrations were not found to be different between clothing ensembles treatments ( $P > 0.05$ ) although levels were slightly higher when wearing the training top (Table 5.4). There was a rise in blood lactate concentration ( $P < 0.05$ ) from pre-exercise to mid-exercise and from pre-exercise to immediately post-exercise in both conditions while at 5 min following exercise the lactate concentration had returned to pre-exercise levels ( $P > 0.05$ ). The concentrations of blood lactate observed immediately post-exercise were lower than the typical concentration of around  $5.0 \text{ mmol l}^{-1}$  recorded post-exercise in elite soccer players (Nielsen *et al.*, 1989; Bangsbo *et al.*, 1991; Bangsbo, 1994a; Bangsbo, 1994b). Blood lactate following competitive matches is individually variable as high intensity activities, such as the maximal sprints seen in soccer activity, are dependent on personal motivation, playing style, tactics and strategy (Bangsbo, 1994a) as well as physical capabilities. The differences in blood lactate are also largely dependent upon the intensity of the activity carried out within the 5 min preceding the drawing of the blood sample.



## 5.5 CONCLUSIONS

The slightly elevated ( $P > 0.05$ ) thermoregulatory and physiological demands generated when wearing a training top may have ramifications for a soccer player in a hot environment where the additional stress of environmental heat may increase demands on heat loss mechanisms beyond an acceptable level.

Wearing the training top may be advantageous when a soccer player would like to keep dry yet still cool in an environment of approximately 20°C. When heat preservation is required in cold and windy conditions the top may not be suitable in preventing overcooling. The intermittent nature of soccer activity may result in periods of sweating during high activity followed by periods of chilling during low activity or static pauses. The design of a suitable clothing ensemble is necessary to address this environmental challenge.



## CHAPTER 6. EFFECTS OF ENVIRONMENT ON THERMOREGULATION



## 6. EFFECTS OF ENVIRONMENT ON THERMOREGULATION

*This chapter contains the results from a study conducted to investigate the physiological, metabolic and thermoregulatory responses to soccer specific intermittent activity in three different environmental conditions.*

### 6.1 INTRODUCTION

The environment consists of everything external to the human body surface and many environmental parameters impact on human physiology and performance. The environmental parameters that affect heat exchange can be termed the “human thermal environment”. Tracy et al. (1986) termed this environment as “a biophysical aggregate of air temperature, wind speed, relative humidity, and radiation”. Considerations of clothing must also be taken in account as garments alter the human thermal environment in creating a microenvironment (Sullivan and Mekjavic, 1992). In this study the parameters of wind speed, relative humidity, radiation, and clothing are kept constant and only air temperature is altered. This control enables the examination of responses to air temperature during soccer specific intermittent exercise.

The effects of a hot environment are reported to reduce performance capacity and time to exhaustion and the effects of a cool environment may also impact on performance. Galloway and Maughan (1997) showed that prolonged exercise at 70%  $\dot{V}O_{2\text{ max}}$  was significantly reduced in a hot environment and that a mild cool environment was beneficial for extending the time to exhaustion. There have been previous studies investigating the responses to intermittent exercise during hot environments (Lind, 1963; Kraning and Gonzalez, 1991) but the research is scarce and is not directly applied to



soccer. This study represents an attempt to quantify the physiological, metabolic and psychophysical demands during soccer specific intermittent exercise.

## **6.2 RESEARCH HYPOTHESES**

Hypothesis 14: Soccer-specific intermittent exercise in different environmental conditions affects physiological demands. Therefore it is hypothesised that:

- a. Heart rate is increased in a warm environment and reduced in a cool environment compared to a neutral environment.
- b. Rating of perceived exertion is increased in a warm environment and reduced in a cool environment compared to a neutral environment.
- c. Thermal perception is increased in a warm environment and reduced in a cool environment compared to a neutral environment.

Hypothesis 15: Soccer-specific intermittent exercise in different environmental conditions affects thermoregulatory demands. Therefore it is hypothesised that:

- a. Core temperature is increased in a warm environment and reduced in a cool environment compared to a neutral environment.
- b. Skin temperature is increased in a warm environment and reduced in a cool environment compared to a neutral environment.



Hypothesis 16: Soccer-specific intermittent exercise in different environmental conditions affects metabolic demands. Therefore it is hypothesised that:

- a. Post-exercise prolactin concentration is increased in a warm environment and reduced in a cool environment compared to a neutral environment.
- b. Blood lactate concentration is increased in a warm environment and reduced in a cool environment compared to a neutral environment.
- c. Blood glucose concentration is increased in a warm environment and unchanged in a cool environment compared to a neutral environment.

### **6.3 METHODOLOGY**

#### **6.3.1 Subjects**

Experiments were conducted on 12 healthy male university students, who were moderately active and participated in soccer training a minimum of once a week. All subjects were considered to be non-acclimatised to any environmental extremes. The mean physical characteristics of the subjects were measured on the first visit to the laboratory and are shown in Table 6.1. All subjects were given written information concerning the practical details, nature, purpose, risks and procedures of the experiment and all freely volunteered for the study. Written informed consent was obtained from each of the participating individuals. The study was approved by the Human Ethics Committee at Liverpool John Moores University and conforms to all policy regarding the use of human subjects.



**Table 6.1.** Mean (*s*) subject physical characteristics.

	Age (years)	Mass (kg)	Height (m)	BMI (kg m <sup>-2</sup> )	$\dot{V}O_{2\max}$ (ml kg <sup>-1</sup> min <sup>-1</sup> )	Surface Area (m <sup>2</sup> ) <sup>a</sup>	% Body Fat <sup>b</sup>
Mean	22	76.9	1.81	23.5	61.4	2.0	15.5
<i>s</i>	5	8.4	0.06	2.0	6.6	0.1	3.3
Range	18-37	66-99	1.7-1.9	20.9-28.0	51.9-70.1	1.8-2.3	10.2-21.6

<sup>a</sup> (Dubois and Dubois, 1916)<sup>b</sup> (Durnin and Womersley, 1974)

### 6.3.2 Exercise and Environmental Conditions

The experiments were conducted in an environmental chamber (RSM Air Conditioning, Liverpool, UK) with temperature and humidity levels controlled. Temperature control was set at 10°C (cool), 20°C (neutral) and 30°C (warm) each with relative humidity at 45%.

Each participant visited the laboratory on 4 separate occasions, at least 3 days apart but conducted at the same time of day to eliminate any circadian variation in performance or thermoregulatory response. Prior to each of the experimental sessions the subjects were asked to refrain from the usual stimulants (page 75). An initial  $\dot{V}O_{2\max}$  assessment was followed by three experimental test conditions. The subjects'  $\dot{V}O_{2\max}$  was recorded using a continuous incremental test on a motorised treadmill (Quinton Instruments, Seattle, USA). Gas was analysed using a breath-by-breath mass spectrometer system (Morgan Medical, Rainham, Kent, UK) with measurements calculated every 15 seconds. All gas volumes were corrected to STPD. Prior to the  $\dot{V}O_{2\max}$  assessment, anthropometric measurements were taken in order to calculate body density, percentage body fat (Durnin and Womersley, 1974), body mass index (BMI = kg m<sup>-2</sup>) and surface area (Dubois and Dubois, 1916). The results are displayed in Table 6.1.



Each subject then returned to the laboratory on three further occasions and was asked to perform 45 min of intermittent exercise in each of the three environmental conditions described above. The conditions were administered to subjects using a Latin square crossover randomisation design. The exercise protocol employed activity patterns specific to outfield soccer players.

The intermittent protocol, illustrated in Figure 3.3, was conducted on a motorised treadmill (Pulsar, HP Cosmos, Nussforf-Traunstein, Germany) and represented the actions of outfield soccer players during match-play conditions. All subjects were familiarised with running on a motorised treadmill and the equipment used.

### **6.3.3 Procedures**

On the day of each trial the subjects reported to the laboratory 30 minutes prior to the trial beginning. Participants wore soccer training clothing ensembles for each session comprising a T-shirt, shorts, socks and training shoes:



**Clothing Ensemble**

Running shoes (subjects own), Socks (Umbro *Comformax*), Underwear (subjects own), Shorts (Umbro, 100% polyester), T-Shirt (Umbro, 100% polyester)



**Plate 6.1.** Illustration of clothing worn during the experimental trials.

Prior to testing, and upon completion, the subjects weighed themselves nude. Following the initial weighing the participant inserted a rectal temperature probe to a depth of 10 cm beyond the anal sphincter to allow continuous measurement of core temperature. The participant then rested in a supine position at which time the thermistors and laser Doppler probes were placed upon the skin with sterile surgical adhesive tape (Transpore, 3M, Michigan, USA). Skin blood flow (SkBF) of the chest, arm, thigh and shin was measured using laser Doppler flowmetry (Periflux, Perimed UK Ltd.) and baseline skin temperature measurements were taken during 10 minutes of supine rest. Venous blood samples were drawn immediately following the initial supine rest and immediately post-exercise for the analysis of energy metabolites [glucose, lactate, nonesterified fatty acids (NEFA)], prolactin, plasma osmolality (pOsm), and change in plasma volume ( $\Delta$ PV) calculated from haematocrit and haemoglobin (Dill and Costill, 1974). All samples were assayed in duplicate. In addition, before the initial nude weighing and after the post nude



weighing, urine samples were taken volume noted and then samples analysed for osmolarity.

#### **6.3.4 Measurements and Analysis**

Heart rate, rectal temperature, mean skin temperature ( $\bar{T}_{sk}$ ) and mean body temperature ( $\bar{T}_b$ ) and environmental temperature were assessed throughout the exercise period and overall heat storage (S) was assessed for each session using the equation of Burton (1935). All procedures are detailed in Chapter 3.

Arterialised capillary blood samples were taken in addition to the venous blood samples on two occasions: mid-test and 5 min post-test. Duplicate 50  $\mu$ l samples of arterialised capillary blood were immediately deproteinized in 100  $\mu$ l of 8% perchloric acid, centrifuged, supernatant removed, placed into fresh tubes, frozen and then later analysed for lactate, glucose and non-esterified fatty acids (NEFA).

During the period of exercise participants were requested to give a ratings of perceived exertion on a scale between 1 to 10 (Borg, 1970) shown in Table 3.2 and ratings of thermal comfort (Nielsen *et al.*, 1989) shown in Table 5.2.

### **6.4 RESULTS**

#### **6.4.1 Environmental Conditions**

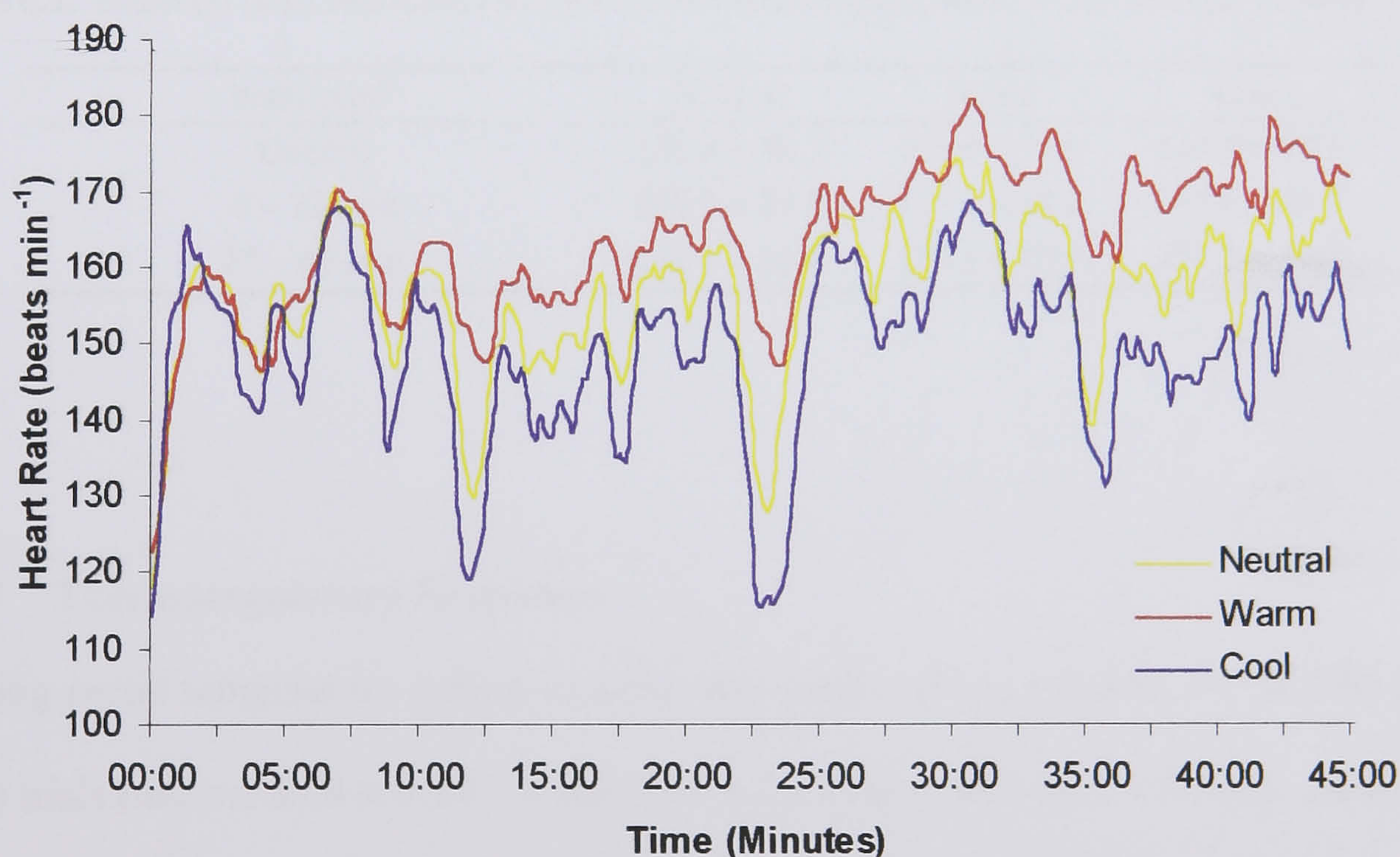
The ambient temperature and humidity was considered stable during all trials. The mean ambient temperature was  $20.6 \pm 1.4^{\circ}\text{C}$ , relative humidity of  $46.5 \pm 6.5\%$  during the neutral conditions;  $10.9 \pm 0.5^{\circ}\text{C}$ , relative humidity of  $48.0 \pm 3.7\%$  during the cool



conditions; and  $29.0 \pm 1.3^{\circ}\text{C}$ , relative humidity of  $40.1 \pm 3.9\%$  during the warm conditions.

#### 6.4.2 Cardiorespiratory Responses

Heart rates increased over the duration of exercise and Figure 6.1 shows the mean heart rate recorded at 15-s intervals during exercise in the three environmental conditions. The overall mean heart rates were  $157 \pm 20 \text{ beats min}^{-1}$ ,  $163 \pm 21 \text{ beats min}^{-1}$  and  $149 \pm 22 \text{ beats min}^{-1}$  for the neutral, warm and cool conditions, respectively.



**Figure 6.1.** Mean heart rate during soccer specific exercise in neutral ( $20^{\circ}\text{C}$ ), warm ( $30^{\circ}\text{C}$ ) and cool ( $10^{\circ}\text{C}$ ) environmental conditions.

The main effect of environment was significantly different ( $F_{2,22} = 26.636$ ,  $P = 0.000$ ) with Tukey's HSD analysis showing overall mean heart rate greater in warm conditions compared to both neutral and cool ( $P < 0.05$ ) and neutral significantly greater than cool



( $P < 0.05$ ). There was also a main effect of time ( $F_{3,151, 34.659} = 29.571$ ,  $P = 0.000$ ) and an interaction of environment  $\times$  time ( $F_{4,186, 46.050} = 3.697$ ,  $P = 0.010$ ). Tukey's HSD tests showed that differences in heart rate were apparent early in the exercise period. The mean heart rate for 0-5 min was lower in the cool environment than both neutral and warm ( $P < 0.05$ ) and this result also occurred for all following time averages. The heart rate for the 5-10 min average was greater in the warm environment than both neutral and cool ( $P < 0.05$ ), this effect was also evident for the rest of the exercise period.

Overall mean values for the total duration of the exercise and split into the first 22 min and last 22 min are displayed in Table 6.2.

**Table 6.2.** Mean ( $s$ ) heart rate values for total duration of exercise, first 22 min and last 22 min.

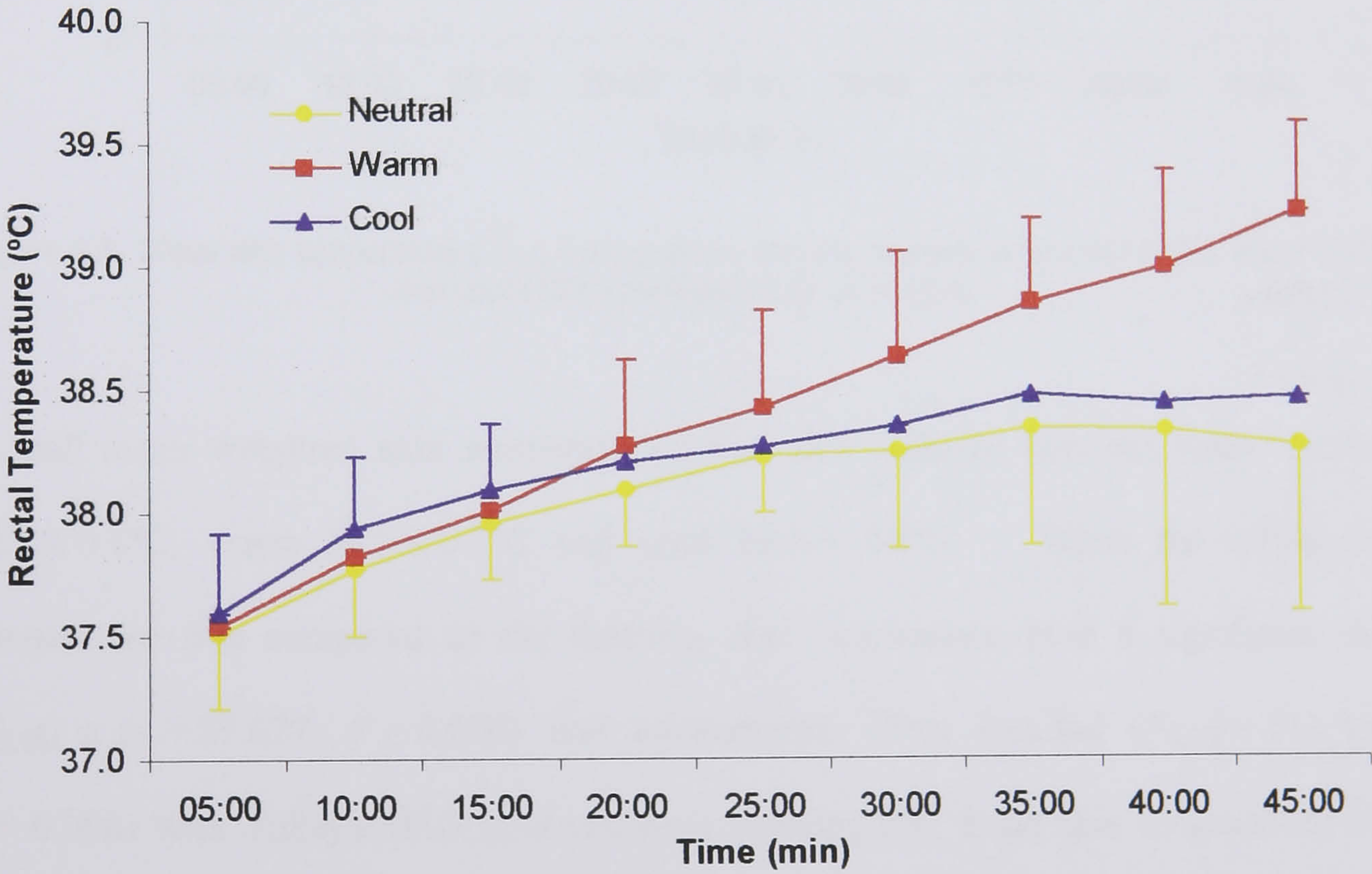
beats min <sup>-1</sup>	Neutral	Warm	Cool
Overall	156.8 $\pm$ 20.2	163.4 $\pm$ 21.0	149.0 $\pm$ 21.5
0 – 22 min	153.2 $\pm$ 19.5	157.8 $\pm$ 19.2	147.6 $\pm$ 21.2
23 – 45 min	161.1 $\pm$ 19.6	170.1 $\pm$ 20.9	151.2 $\pm$ 21.2

### 6.4.3 Thermoregulatory Responses

Resting rectal temperature before exercise was similar ( $F_{2,22} = 2.240$ ,  $P = 0.130$ ) in the three trials (neutral  $37.4 \pm 0.3^{\circ}\text{C}$ , warm  $37.5 \pm 0.3^{\circ}\text{C}$  and cool  $37.5 \pm 0.3^{\circ}\text{C}$ ). At the end of the exercise periods the rectal temperatures were different ( $F_{2,22} = 10.788$ ,  $P = 0.001$ ): neutral  $38.3 \pm 0.7^{\circ}\text{C}$ , warm  $39.2 \pm 0.3^{\circ}\text{C}$  and cool  $38.4 \pm 0.3^{\circ}\text{C}$ . There was not an overall main effect for environmental treatment ( $F_{2,22} = 2.447$ ,  $P = 0.110$ ). The increase in core temperature over the duration of exercise in each environment was significant ( $F_{8,88} = 94.181$ ,  $P = 0.000$ ) and there was an interaction between the effect of environment and the effect of the exercise duration ( $F_{16,176} = 6.045$ ,  $P = 0.003$ ). The

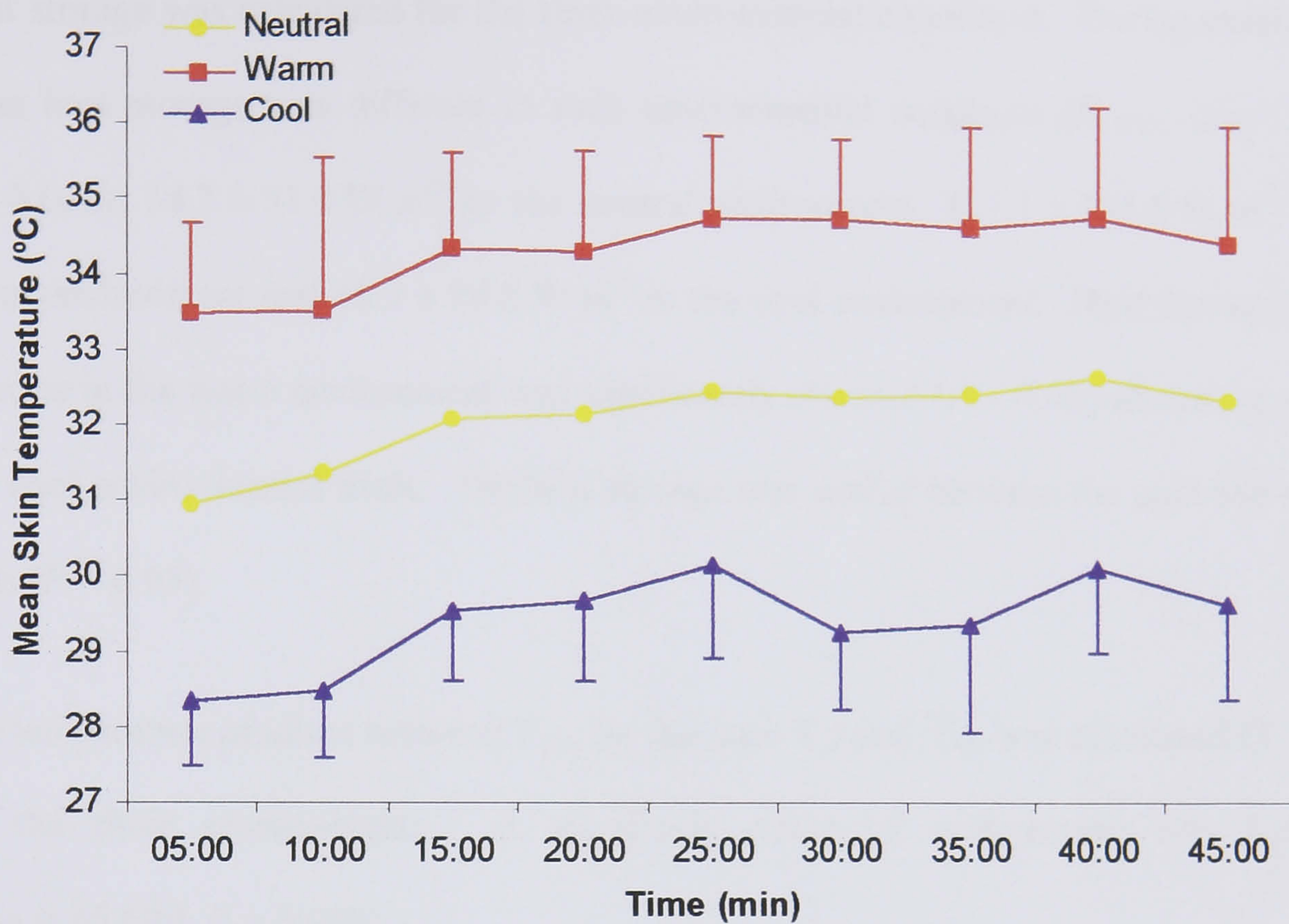


response of rectal temperature to environment was to increase more when exercising in a hot environment. Temperatures during neutral and cool environments were similar throughout the exercise period until approximately 30 min into the protocol. Tukey's HSD post-hoc have indicated higher rectal temperature during exercise in the warm conditions compared to both neutral and cool environments ( $P < 0.05$ ) at time-point means for 35 (calculated from 30-35 min) , 40 (35-40 min) and 45 (40-45 min) min.



**Figure 6.2.** Mean (*s*) rectal temperature (°C) during soccer specific exercise in neutral (20°C), warm (30°C) and cool (10°C) environmental conditions.





**Figure 6.3.** Mean skin temperature ( $\bar{T}_{sk}$ ) during soccer specific exercise in neutral (20°C), warm (30°C) and cool (10°C) environmental conditions.

Overall mean weighted skin temperature ( $\bar{T}_{sk}$ ) was different between trials: Neutral  $32.1 \pm 0.6^\circ\text{C}$ , warm  $34.5 \pm 0.7^\circ\text{C}$  and cool  $29.4 \pm 0.6^\circ\text{C}$ . When the initial skin temperature was compared to the finishing skin temperature both a significant time ( $F_{2.861, 31.473} = 27.627$ ,  $P = 0.000$ ) and environment effect resulted ( $F_{2, 22} = 112.357$ ,  $P = 0.000$ ) with Tukey's HSD post-hoc tests showing that mean skin temperature was elevated in the warm environment above both neutral and cool responses ( $P < 0.05$ ), and significantly lower in the cool environment compared to the other environmental conditions ( $P < 0.05$ ). Post-hoc comparisons with time averages showed that a significant increase in temperature was found after 15 min of exercise ( $P < 0.05$ ). There was no time  $\times$  environment interaction ( $F_{5.202, 57.221} = 0.726$ ,  $P = 0.612$ ).



Heat storage was calculated for the three environmental conditions. During exercise the mean heat storage was different in each environmental condition ( $F_{1,240, 13.642} = 5.598$ ,  $P = 0.028$ );  $54.7 \pm 51.4 \text{ W m}^{-2}$  in the neutral environment,  $117.1 \pm 135.5 \text{ W m}^{-2}$  in the warm environment and  $48.3 \pm 20.8 \text{ W m}^{-2}$  in the cool environment. Heat storage during exercise in the warm environment was significantly elevated ( $P < 0.05$ ) above the neutral and cool environmental trials. The heat storage was similar between the cool and neutral trials ( $P > 0.05$ ).

The temperature gradient between  $T_{\text{core}}$  (in this case  $T_r$ ) and  $\bar{T}_{\text{sk}}$  was calculated ( $T_r - \bar{T}_{\text{sk}}$ ) for the three environments. A significant effect of environment was indicated ( $F_{2,22} = 85.699$ ,  $P = 0.000$ ).

Sweating characteristics were also different between the environmental trials. Total sweat production rate ( $F_{2,22} = 4.559$ ,  $P = 0.022$ ), absolute sweat in clothing ( $F_{1,167, 12.840} = 17.142$ ,  $P = 0.000$ ), and percentage of total sweat lost retained in clothing increased ( $F_{2,22} = 4.879$ ,  $P = 0.018$ ) with increasing environmental temperature (Table 6.3).

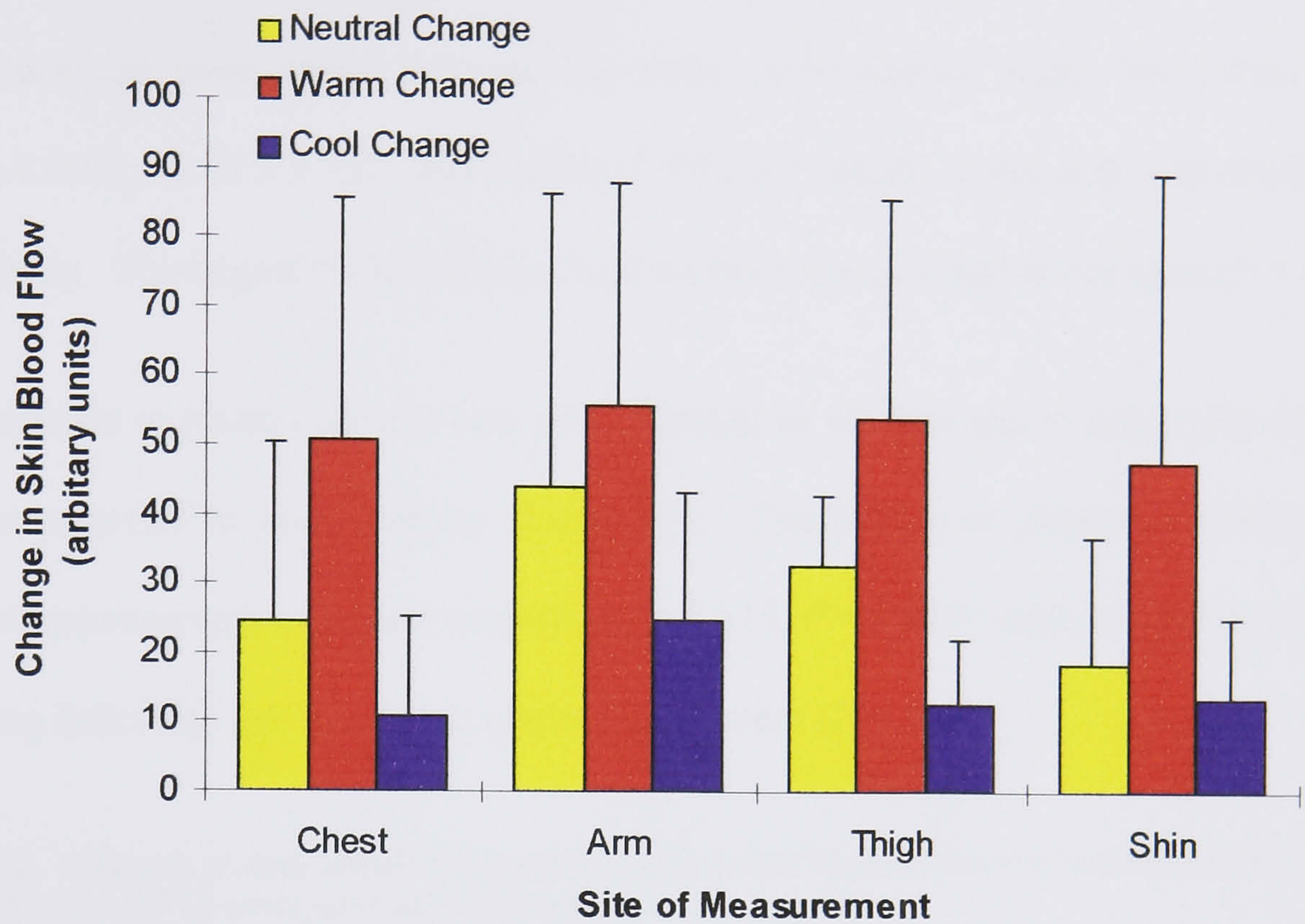
**Table 6.3.** Sweat losses and accumulation of sweat within clothing.

	Neutral	Warm	Cool
Body mass loss (kg)	$1.2 \pm 0.7$	$1.5 \pm 1.2 *$	$0.7 \pm 0.4$
Body mass loss (%)	$1.6 \pm 0.8$	$2.0 \pm 1.5 *$	$0.9 \pm 0.5$
Sweat rate ( $\text{l h}^{-1}$ )	$1.6 \pm 0.9$	$2.0 \pm 1.5 *$	$0.9 \pm 0.5$
Total sweat in clothing (g)	$81.4 \pm 51.2$	$207.5 \pm 122.2 *$	$38.5 \pm 32.3$
Sweat loss retained in clothing (%)	$9.6 \pm 10.3$	$18.8 \pm 14.2 *$	$6.8 \pm 5.4$

\* greater than both neutral and cool conditions,  $P < 0.05$

Post-hoc Tukey's confirmed that the warm condition provoked a higher sweat loss than either the neutral or cool environments ( $P < 0.05$ ).





**Figure 6.4.** Mean change (*s*) in skin blood flow following soccer specific exercise in neutral (20°C), warm (30°C) and cool (10°C) environmental conditions.

Increases in skin blood flow (Figure 6.4) were repeatedly different between environmental trials ( $F_{2, 22} = 21.071, P = 0.000$ ) with the smallest change occurring in the cool environment, followed by neutral and then warm. ( $P < 0.05$ ). There were also differences between the sites measured ( $F_{3, 33} = 7.287, P = 0.001$ ) and Tukey's HSD tests signified that the change in skin blood flow was larger at the chest site than the two lower body sites (thigh and shin) ( $P < 0.05$ ), additionally the site of measurement at the arm was greater than the shin ( $P < 0.05$ ). An interaction between effect of environment and time ( $F_{2, 22} = 18.749, P = 0.000$ ) occurred in the case of post-exercise skin blood flow, with the neutral and cool environments being less than post-exercise skin blood flow in the warm environment ( $P < 0.05$ ). No interactions were found for site  $\times$  environment, site  $\times$  time, or site  $\times$  environment  $\times$  time ( $P > 0.05$ ).



#### 6.4.4 Plasma Volume and Osmolality

Significant differences ( $F_{2, 22} = 6.862$ ,  $P = 0.005$ ) in plasma volume changes from rest to end of exercise were found between the three environmental trials: the values were  $-6.79 \pm 4.00\%$ ,  $-9.68 \pm 3.72\%$  and  $-5.96 \pm 3.32\%$  for neutral, warm and cool conditions, respectively. The largest difference occurred between the cool and warm trials ( $P < 0.05$ ).

The reduction in plasma volume was also reflected by the increase in osmolality (mosm) from pre-exercise to post-exercise (Table 6.4). The change in plasma osmolality was different between environmental trials ( $F_{2, 16} = 5.515$ ,  $P = 0.015$ ) with the greatest change occurring following exercise in the warm environment ( $P < 0.05$ ).

**Table 6.4.** Mean (*s*) plasma osmolality (mosm) during soccer specific exercise in neutral (20°C), warm (30°C) and cool (10°C) environmental conditions.

	Pre-exercise	Post-exercise	Change
<i>Osmolality (mosm)</i>			
Neutral	$301.8 \pm 5.5$	$306.2 \pm 3.4$	$4.4 \pm 4.1$
Warm	$299.5 \pm 6.7$	$313.6 \pm 8.8$	$14.0 \pm 7.5$ *
Cool	$302.7 \pm 6.6$	$308.7 \pm 4.9$	$5.7 \pm 4.1$

\* greater change than both neutral and cool conditions,  $P < 0.05$

#### 6.4.5 Blood Metabolites

Blood metabolites during the soccer specific intermittent exercise in neutral, warm and cool environments are shown in Table 6.5 and Table 6.6. The concentrations of lactate changed over the duration of the exercise ( $F_{3, 33} = 35.284$ ,  $P = 0.000$ ) and differences between environmental trials were nearing significance ( $F_{2, 22} = 3.169$ ,  $P = 0.062$ ). There was also an environment  $\times$  time interaction ( $F_{6, 66} = 2.266$ ,  $P = 0.048$ ).



**Table 6.5.** Blood lactate concentration (mean  $\pm$  s) during soccer specific exercise ( $\text{mmol l}^{-1}$ ) in neutral ( $20^{\circ}\text{C}$ ), warm ( $30^{\circ}\text{C}$ ) and cool ( $10^{\circ}\text{C}$ ) environmental conditions.

	Pre	Mid-Exercise	Post-Exercise	Post-Exercise
<i>Lactate (<math>\text{mmol l}^{-1}</math>)</i>				
Neutral	$0.7 \pm 0.3$	$3.7 \pm 2.0$	$2.4 \pm 2.4$	$2.7 \pm 1.7$
Warm	$0.9 \pm 0.4$	$3.6 \pm 1.7$	$2.6 \pm 1.5$	$2.6 \pm 1.6$
Cool	$0.8 \pm 0.2$	$4.2 \pm 2.2$	$1.8 \pm 1.0$	$1.9 \pm 1.3$

Blood glucose concentrations were not different between environmental trials ( $F_{2,20} = 2.233$ ,  $P = 0.133$ ) or over the duration of exercise ( $F_{1,10} = 0.023$ ,  $P = 0.881$ ). Additionally there was no statistical interaction between environment and time effects ( $F_{2,20} = 2.381$ ,  $P = 0.118$ ). The NEFA concentrations were also not different between environmental conditions ( $F_{2,20} = 2.926$ ,  $P = 0.077$ ) and did not result in a environment  $\times$  time interaction ( $F_{2,20} = 1.453$ ,  $P = 0.258$ ); however, the change in NEFA concentration was significant over time ( $F_{1,10} = 46.109$ ,  $P = 0.000$ ). When post-exercise measurements of NEFA and glucose were corrected for plasma volume loss and re-analysed, there was no effect on the statistical results.



**Table 6.6.** Glucose, NEFA and prolactin concentrations (mean  $\pm$  s) pre and post exercise in neutral (20°C), warm (30°C) and cool (10°C) environmental conditions.

	Pre-Exercise	Post-Exercise	Change
<i>Plasma Glucose (mmol l<sup>-1</sup>)</i>			
Neutral	5.5 $\pm$ 0.6	5.2 $\pm$ 0.5	-0.3 $\pm$ 0.5
Warm	5.4 $\pm$ 1.1	5.8 $\pm$ 1.0	0.4 $\pm$ 0.8
Cool	5.2 $\pm$ 0.7	5.0 $\pm$ 0.6	-0.2 $\pm$ 0.9
<i>Plasma NEFA (<math>\mu</math>mol l<sup>-1</sup>)</i>			
Neutral	289.4 $\pm$ 185.5	697.6 $\pm$ 302.6	415.8 $\pm$ 345.1 *
Warm	493.2 $\pm$ 324.7	949.1 $\pm$ 492.6	455.1 $\pm$ 358.9 *
Cool	352.8 $\pm$ 212.7	600.4 $\pm$ 262.9	247.6 $\pm$ 162.8 *
<i>Serum Prolactin (mIU l<sup>-1</sup>)</i>			
Neutral	161.1 $\pm$ 77.4	361.8 $\pm$ 152.6	200.7 $\pm$ 152.4
Warm	225.1 $\pm$ 91.8	741.2 $\pm$ 602.4	516.1 $\pm$ 577.2 *
Cool	178.3 $\pm$ 92.0	202.9 $\pm$ 88.6	24.6 $\pm$ 69.6

\* significant change from pre-exercise to post-exercise,  $P < 0.05$

Statistical analysis using ANOVA and Tukey's HSD showed a significant effect of environment  $\times$  time for serum prolactin concentration ( $F_{1,151, 9.207} = 5.575$ ,  $P = 0.038$ ). The Tukey's HSD differences in prolactin concentration showed that the changes from pre-exercise to post-exercise were not significant in the neutral ( $P > 0.05$ ) or cool ( $P > 0.05$ ) environments. Post-exercise concentrations were greater in the warm environment compared to neutral ( $P < 0.05$ ), and cool ( $P < 0.05$ ) environments.

A main effect of environment of prolactin was significant ( $F_{1,130, 9.042} = 5.788$ ,  $P = 0.037$ ) with prolactin greater in the warm than in both the neutral environment ( $P < 0.05$ ), and cool environment ( $P < 0.05$ ). The change in prolactin concentration over the duration of the exercise also resulted in a significant main effect ( $F_{1,8} = 9.551$ ,  $P = 0.015$ ). Further analysis was carried out correlating prolactin concentration with several relevant parameters (Table 6.7).



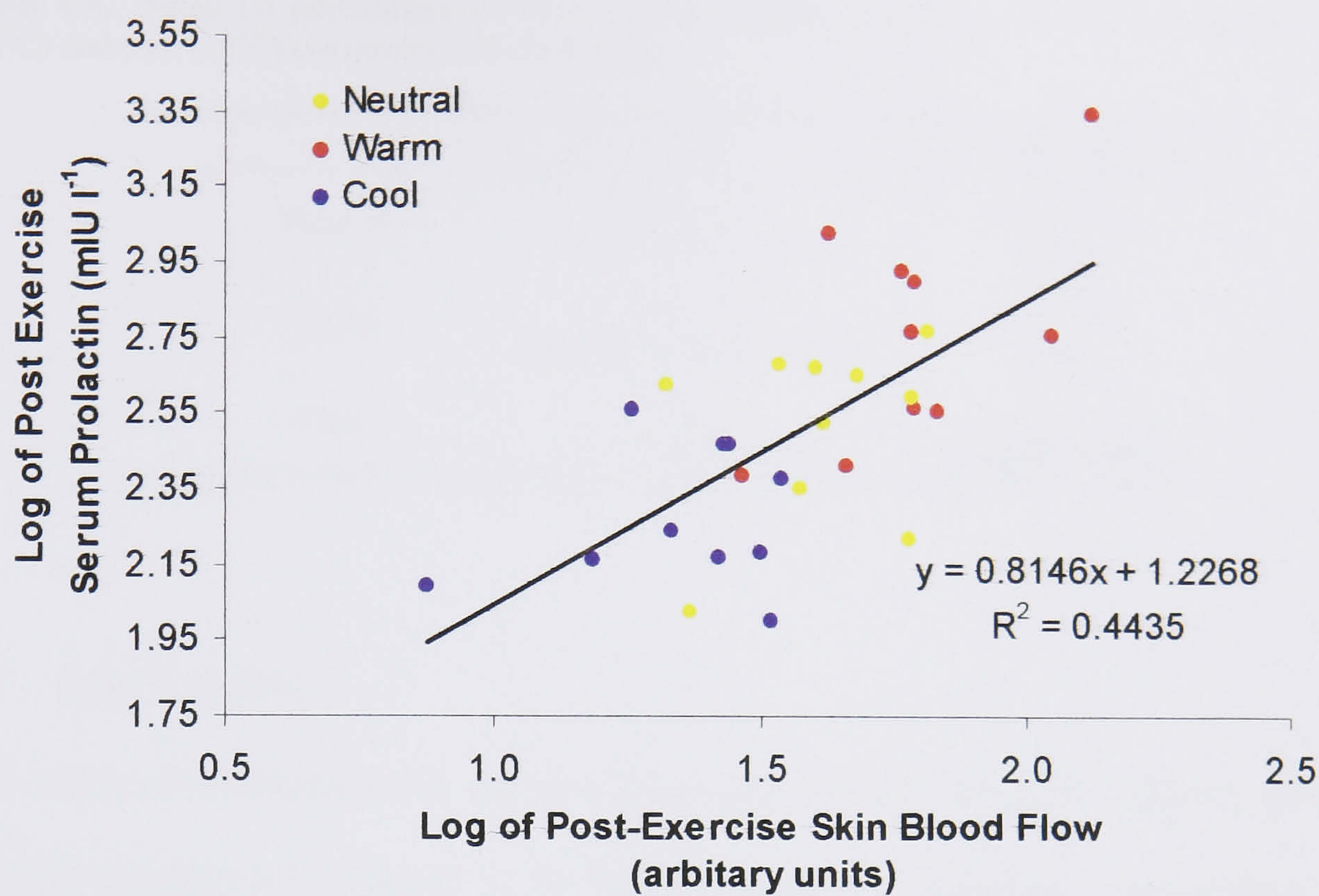
**Table 6.7.** Pearson correlation coefficients of prolactin concentration with other relevant parameters.

Correlation	<i>R</i>	<i>P</i>
<i>Relationships with temperatures</i>		
Post-exercise [prolactin] vs. ambient °C	0.53	**
Post-exercise [prolactin] vs. end rectal temperature ( $T_r$ )	0.57	**
Log Post-exercise [prolactin] vs. log end $T_r$	0.67	**
Post-exercise [prolactin] vs. end mean skin temperature ( $\bar{T}_{sk}$ )	0.32	NS
Post-exercise [prolactin] vs. end temperature gradient ( $T_{gradient}$ )	-0.26	NS
Post-exercise [prolactin] vs. end mean body temperature ( $\bar{T}_b$ )	0.48	**
<i>Relationships with cardiovascular parameters</i>		
Post-exercise [prolactin] vs. post-exercise (SkBF)	0.73	**
Log post-exercise [prolactin] vs. log post-exercise SkBF	0.68	**
Post-exercise [prolactin] vs. post-exercise plasma osmolality	0.47	*
$\Delta$ [prolactin] vs. $\Delta$ plasma volume	-0.41	*
Post-exercise [prolactin] vs. max heart rate	0.44	*
Post-exercise [prolactin] vs. heart rate range	0.46	**
<i>Relationships with psychophysical measures</i>		
Post-exercise [prolactin] vs. end rating of perceived exertion	0.27	NS
Post-exercise [prolactin] vs. end perceived thermal comfort	0.37	*

NS =  $P > 0.05$ , \* =  $P < 0.05$ , \*\* =  $P < 0.01$ 

The strongest correlation resulted from plotting serum prolactin concentration at the completion of exercise against the post-exercise skin blood flow (Figure 6.5). The data were heteroscedastic for this relationship along with the relationship with core temperature. Therefore the data were transformed by taking logarithms, thereby controlling heteroscedastic errors and the resultant homogeneity of variance allows the achievement of a more reliable correlation coefficient (Nevill, 1997).





**Figure 6.5.** Linear correlation of post-exercise serum prolactin concentration with post-exercise mean skin blood flow, combining data from all three environmental conditions.

**6.4.6 Psychophysical Ratings**

Overall mean ratings of perceived exertion and thermal perception and the corresponding descriptions are displayed in Table 6.8. There was a relationship between environmental trial and both perceived exercise intensity ( $F_{2,22} = 8.970, P = 0.001$ ) and perceived thermal comfort ( $F_{1,126, 11.265} = 40.727, P = 0.000$ ). Perceived exertion also showed a significant change over time ( $F_{8,88} = 41.312, P = 0.000$ ) and an interaction between environment trial and time ( $F_{5.503, 60.528} = 6.288, P = 0.000$ ). Thermal perception increased over time ( $F_{5.428, 54.278} = 45.168, P = 0.000$ ) but did not report an interaction between trial and time ( $F_{7.604, 76.042} = 1.298, P = 0.259$ ).



**Table 6.8.** Mean (s) psychophysical ratings during soccer specific exercise in neutral (20°C), warm (30°C) and cool (10°C) environmental conditions.

	RPE	Thermal Perception
Neutral	3.9 ± 1.1 (somewhat hard)	6.9 ± 1.1 (warm)
Warm	4.6 ± 1.9 (somewhat hard / hard)	8.0 ± 1.0 (hot)
Cool	3.3 ± 1.0 (moderate)	5.6 ± 1.2 (slightly warm)

## 6.5 DISCUSSION

This study demonstrates, for the first time, that the physiological response to soccer-specific intermittent exercise is dependent upon environmental temperature. This supports previous findings for endurance exercise that showed a reduction in time to exhaustion when performing prolonged endurance exercise and high intensity intermittent exercise (Galloway and Maughan, 1997; Morris *et al.*, 1998).

The heart rate profile displayed in Figure 6.1 illustrates the cardiovascular drift associated with exercise in a hot environment. Cardiovascular drift is the phenomenon of progressively increased heart rate associated with exercise in a hot environment (Boutcher *et al.*, 1995; Coyle, 1998). As skin blood flow increases, central blood volume decreases and less blood returns to the heart. To compensate for the lower stroke volume, and to maintain cardiac output and therefore mean arterial pressure, heart rate increases. When heart rate is averaged over the first 22 min and second 22 min separately (Table 6.2), the effects of this drift become more apparent. Mean heart rate during both periods of exercise in the cool trial was almost identical whereas during the same activity in the neutral and warm trials there was a distinctly increased heart rate in the second phase of the exercise. The increase in heart rate was more marked during exercise in the warm



trial. The mean heart rate values recorded in this study equate to heart rates found by other research groups for soccer match-play (Van Gool *et al.*, 1988; White *et al.*, 1988; Bangsbo, 1994b; Reilly, 1996c).

Overall mean  $\dot{V}O_{2\text{ max}}$  is  $61.5 \pm 7.0 \text{ ml kg}^{-1} \text{ min}^{-1}$  which is above average for this age group of male university athletes (Wilmore and Costill, 1999) and the range of  $52 - 70 \text{ ml kg}^{-1} \text{ min}^{-1}$  is similar to the range reported for elite soccer players (Kirkendall, 1985; Mercer *et al.*, 1995; Dunbar and Power, 1995; Reilly, 1996b; Rodriguez and Iglesias, 1998a). Considering the large anaerobic demands of soccer during sprints, extremely high  $\dot{V}O_{2\text{ max}}$  values concomitant with elite aerobic endurance should not be expected. Nevertheless, good endurance performance is required for soccer activity and higher than average  $\dot{V}O_{2\text{ max}}$  values are usually observed.

Due to technical problems with the equipment,  $\dot{V}O_2$  was accurately measured in only two neutral sessions. The two mean values obtained were 69.2% and 61.6%  $\dot{V}O_{2\text{ max}}$  and maxima of 92.9% and 84.0%, respectively. Overall intensity was equivalent to  $65.4 \pm 14.5\%$  of  $\dot{V}O_{2\text{ max}}$ . Although no conclusions can be obtained from this incomplete set of data, it can be noted that the values obtained are somewhat lower than estimated mean values of 70% to 75%  $\dot{V}O_{2\text{ max}}$  obtained during actual match-play (Bangsbo, 1994a; Bangsbo, 1994b; Reilly, 1996c). It should also be noted that the two participants had  $\dot{V}O_{2\text{ max}}$  measurements of  $70.1 \text{ ml kg}^{-1} \text{ min}^{-1}$  and  $69.8 \text{ ml kg}^{-1} \text{ min}^{-1}$  at the top of the range for this population sample. However, heart rate means have been shown to be similar to those previously found during actual match-play. Overestimation of predicted  $\dot{V}O_2$  during soccer match-play by as much as 15% has been reported (Rodriguez and Iglesias,



1998a) which may explain the differences between the recorded mean %  $\dot{V}O_{2\max}$  during this investigation and that estimated from actual match-play.

Rectal temperature was not different at the start of exercise and temperature during the three environmental trials increased simultaneously for the first 20-25 min of exercise. After this time point rectal temperature became disparate in the warm trial with a continued increase (Figure 6.2). Core temperature in the cool and neutral trials did not increase at the same rate, but tended to show a plateau. It is interesting to note that the core temperature in the cool trial was slightly higher ( $P > 0.05$ ) than that of the neutral trial. This difference may be due to cold induced peripheral vasoconstriction increasing the central blood volume and maintaining core temperature above expected levels. Heat storage was slightly greater ( $P > 0.05$ ) in the neutral condition at  $53.1 \pm 54.2 \text{ W m}^{-2}$  compared to  $45.5 \pm 19.6 \text{ W m}^{-2}$  in the cool trial. Therefore the heat content of the body was lower during the cool trial despite an elevated core temperature due to the decreased skin temperature. Heat storage during the warm trial was significantly higher ( $P < 0.05$ ) at  $121.3 \pm 147.9 \text{ W m}^{-2}$  than both neutral and warm due to the combined elevated skin and core temperatures. Heat storage indicates if there is a net gain or loss to the environment. In each trial there was a positive gain and therefore the participants were unable to transfer all the metabolic heat produced to the surrounding environment.

The significant differences in  $T_r$  cannot be accounted for by changes in clothing as the participants wore identical clothing ensembles during trials to ensure only the different environment would cause any resultant differences in thermoregulation.

Skin temperature was immediately greater in the warm environment and lowest in the cool environment compared to the neutral environment ( $P < 0.05$ ) at the start of exercise,



which is due to the initial 5 minutes of warm-up preceding the exercise period allowing an initial response to the prevailing conditions. Significant differences in skin temperature remained throughout the duration of the trials ( $P < 0.05$ ). Boutcher *et al.* (1995) showed a similar profile of skin temperature responses to different environmental conditions.

An increase in core temperature causes an increase in sweat rate (Ogawa, 1984), and it is not surprising, therefore, that the exercise in the warm environment caused a greater production of sweat. These effects were demonstrated by the increased sweat accumulation during activity in the warm environment and are displayed in Table 6.3. Loss of body mass due to sweat production was not different ( $P > 0.05$ ) between conditions at  $1.6 \pm 0.8\%$ ,  $0.9 \pm 0.5\%$ , and  $2.0 \pm 1.5\%$  during exercise in neutral, warm and cool trials, respectively. This amount of dehydration is considered to be relatively mild (Barr, 1999) but even mild dehydration may reduce exercise performance (Maughan and Leiper, 1994; Shi and Gisolfi, 1998). The effects of dehydration are demonstrated by the large ( $P < 0.05$ ) reductions in plasma volume and concomitant increases in plasma osmolality (Table 6.4) during exercise in the heat in this study.

The accumulation of sweat within the clothing ensemble is affected by the thermal strain of the environment. More sweat accumulated in the clothing ensemble during the warm trial and least during the cool trial ( $P < 0.05$ ). During exercise in the heat, if sweat is retained in the clothing without being evaporated there is a reduction in heat loss through evaporation and hence thermal comfort is decreased.

Reduced plasma volume (Table 6.4) and increased plasma osmolality reflect a reduced blood volume due to dehydration, which exacerbates the cardiovascular drift - a



progressive increase in heart rate - in an attempt to maintain cardiac output (Coyle, 1998). The conflicting demands of skin blood flow and muscle blood supply is exacerbated by loss of fluid in the warm environment. Reduced central blood volume has serious effects on performance capacity and time to fatigue (Rowell, 1983b). Large demands on cardiac output, especially during conditions of dehydration, cannot be compensated in a hot environment resulting in insufficient blood supply reaching the working muscle. The reduction in muscle blood flow leads to elevated demands on anaerobic metabolism, resulting in increased blood lactate concentration (González-Alonso *et al.*, 1998).

Exercise in the cool (10°C) environment showed metabolic differences ( $P < 0.05$ ) compared to the same activity in a neutral (20°C) environment. Blood lactate concentration was elevated mid-exercise during soccer specific intermittent exercise in a cool environment at 4.3 mmol l<sup>-1</sup> compared to 3.7 mmol l<sup>-1</sup> and 3.9 mmol l<sup>-1</sup> for neutral and warm environments, respectively. Blomstrand *et al.* (1986) have reported similar effects, with cool conditions causing increased levels of lactate accumulation within muscle compared to a normal environment. Differences in blood lactate concentration may be due to increased accumulation, decreased elimination or a combination of the two factors. It is suggested that there is increased dependence upon anaerobic metabolism in cooled muscle, which results in a more rapid accumulation of lactate and earlier time to fatigue. Reduced splanchnic blood flow may prevent adequate elimination of lactate in the liver. In contrast to the high mid-exercise blood lactate, post-exercise blood lactate concentration in this study was lowest following exercise in the cool environment both immediately post-exercise and 5 min post-exercise. Similar concentrations of blood lactate were measured following neutral (2.55 and 3.00 mmol l<sup>-1</sup> for 0 min post-exercise and 5 min post-exercise respectively) and warm (2.83 and 2.77 mmol l<sup>-1</sup> for 0 min



post-exercise and 5 min post-exercise respectively) trials. Soccer specific intermittent exercise in a cool environment may have an overall lower metabolic demand than the same exercise in neutral and warm environments. Although the mid-exercise concentrations of lactate were higher in the cool environment, the accumulated lactate may be cleared faster following exercise. Following exercise in the cool condition, extra blood flow to the skin for heat dissipation is not required, hence allowing sufficient blood flow to the liver to allow lactate elimination.

Thermogenesis increases metabolism and heat production but the intensity of exercise during the exercise protocol is sufficient to balance heat loss with heat gain and maintain core temperature (Pugh, 1967). During the cold trial, possible peripheral cooling may have stimulated localised thermogenesis, but this is unlikely due to the presence of a slight increase in post-exercise skin blood flow. Therefore, elevated blood lactate concentration can not be accounted for by means of thermogenesis. Conflicting demands of blood flow in warm conditions may remain post-exercise as waste metabolites such as lactate are still being removed from the muscle while heat loss is necessitated to bring the body back to a pre-exercise state. These conflicting demands are not prevalent during exercise in a cool environment as the change in skin blood flow was significantly less during exercise in the cool environment ( $P < 0.05$ ) and hence the majority of cardiac output is directed to the muscle, allowing quicker recovery and removal of lactate.

Blood glucose concentrations were not different between trials ( $P > 0.05$ ) or over time ( $P > 0.05$ ). This may suggest that muscle glycogen requirements are met directly with high intensity activity bouts compensated for during low intensity activity bouts (Christmass *et al.*, 1999a; Christmass *et al.*, 1999b).



Blood concentrations of nonesterified fatty acids (NEFA) were not significantly different between trials ( $P = 0.08$ ) but the increase in concentration from before exercise to post exercise was significant ( $P < 0.01$ ). Increased concentration of NEFA suggests that fat utilisation is contributing to the energy provision during soccer specific intermittent exercise. This contribution is to be expected to occur mainly during the low to moderate intensity activity periods with carbohydrate provision dominant during high activity bouts. The contribution of fat metabolism during activity is not affected by the environmental conditions, conflicting with previous findings (Timmons *et al.*, 1985). The conclusions from that study resulted from experiments carried out in severe cold conditions of  $-10^{\circ}\text{C}$ ,  $20^{\circ}\text{C}$  lower than the cool trial in this study.

Exercise at core temperature greater than  $38^{\circ}\text{C}$  has been reported to reduce central drive for motor performance contributing to onset of fatigue. The resulting adverse effect on the central nervous system (Nielsen *et al.*, 1990) has been related to central serotonergic (5-hydroxytryptamine; 5-HT) activity (Blomstrand *et al.*, 1988; Davis and Bailey, 1997). Both 5-HT (Strachan and Maughan, 1999) and dopamine (Mills and Robertshaw, 1981; Colthorpe *et al.*, 1998) release have been linked to increased blood prolactin concentration.

Mills *et al.* (1981) performed an analysis of the response of plasma prolactin to changes in mean body temperature and found a strong correlation ( $r = 0.96$ ). In contrast to this study, the experiment of Mills *et al.* (1981) was carried out on resting participants. The correlations carried out in this study (Table 6.7) also include a significant relationship between the post-exercise prolactin concentration and mean body temperature ( $\bar{T}_b$ ) at the end of exercise, although the strongest relationship existed between post-exercise



prolactin and post-exercise skin blood flow. There was also a significant relationship ( $P < 0.05$ ) between rectal temperature and prolactin concentration at the end of exercise, shown in Figure 6.5, suggesting that the release of prolactin is also a function of heat stress. The regulation of blood volume may be the stimulatory factor for the release of prolactin as evidence has been presented for prolactin as a regulator of fluid (Horrobin, 1980) and as a modulator of chloride ions in sweat (Robertson *et al.*, 1986). Both roles would explain the significantly different ( $P < 0.05$ ) prolactin concentrations in response to the three different environmental conditions and the strong relationships between all the cardiovascular parameters in this study. The distinct lack of a change in prolactin concentration when exercising in the cold environment is corroborated by previous work which reported inhibition of prolactin release under cool conditions (Brisson *et al.*, 1989) and suggests that the reported link between fatigue during exercise in the heat and prolactin is not coincidental (Mills and Robertshaw, 1981).

The perception of environmental temperature was assessed through the use of a thermal perception ballot (Nielsen *et al.*, 1989). Humidity cannot be sensed through the skin but skin wettedness can be perceived impacting upon thermal comfort while the garments worn also affect thermal perception (Gwosdow *et al.*, 1986; Nielsen and Endrusick, 1990). The differences ( $P < 0.05$ ) between environmental conditions show the sensitive perception of the thermal environment. Overall thermal perception during exercise in the cool environment resulted in a value equating to "slightly warm". Therefore the level of activity was sufficient to offset the effects of cold stress as described by Pugh (1966; 1967) where he suggested that maintaining activity at 50-60% of  $\dot{V}O_{2\text{ max}}$  would offset any negative effects of heat loss in a cold environment. This view has been supported by more recent work (Weller *et al.*, 1997) which showed that exercise greater than 60%



$\dot{V}O_{2\max}$  will offset any performance impairment at 5°C. At the same time the rating of perceived exertion during the cool trial was lower than either the neutral trial or warm trial, suggesting that performing soccer specific intermittent exercise in cool environment of 10°C may be optimal. This opinion is supported by previous research (Galloway and Maughan, 1997).

It may be that the thermal perception scale suffered from a "ceiling effect" where the subjects reached the maximal point on the scale "9 - Very Hot" before they truly reached a maximal thermal condition. The future development of a wider thermal perception scale would address this limitation. Tolerance of heat combined with exercise is determined more by psychological strain than physiological demands (Aoyagi *et al.*, 1998).

## 6.6 CONCLUSION

The thermoregulatory and physiological demands generated when exercising in a warm environment have ramifications for a soccer player travelling to an unfamiliar climate and preparations such as heat acclimatisation would be beneficial. Environmental heat may increase demands on heat loss mechanisms beyond an acceptable level while playing soccer in a cool environment appears to be optimal for physiological, metabolic and thermoregulatory demands.

Analysis revealed that many differences in physiological parameters between environmental conditions were significant ( $P < 0.05$ ). Soccer-specific intermittent exercise is physiologically more demanding in a hot environment while the effect of a cool environment was physiologically optimal in the conditions of this experiment.



## CHAPTER 7. EFFECTS OF CLOTHING AND ENVIRONMENT ON THERMOREGULATION



## 7. EFFECTS OF CLOTHING AND ENVIRONMENT ON THERMOREGULATION

*Given the observations of greater thermal strain during exercise in the heat in the previous chapter, this final chapter examines the efficacy of technical sportswear in reducing thermal strain in a warm (30°C) environment. Currently available soccer training clothing were examined in two compositions; traditional polyester and technical 'moisture management' polyester.*

### 7.1 INTRODUCTION

Performance of intermittent activity in a warm (~30°C) environment has been shown to be reduced by ~21% (Morris *et al.*, 1998). A reduction in time to exhaustion when exercising in a hot environment is due to core temperature reaching a critically high value (Teller *et al.*, 1998; González-Alonso *et al.*, 1999). As the core temperature increases the sweating response is activated and sweat production increases. The amount of sweat that evaporates from the skin and dissipates heat is dependent upon the gradient of water vapour pressure between the skin and the ambient environment. Clothing is a barrier to this gradient and will affect heat dissipation (Bernard and Matheen, 1999). The flow of air through the microenvironment is important for ventilation and impacts upon the three main pathways for heat loss: sensible (dry) heat across the clothing, sensible heat through the air in the micro-environment and insensible (vapour) heat transferred by evaporation of sweat into the micro-environment and out into the ambient air (Birnbaum and Crockford, 1978). Ventilation has a large impact on both sensible and insensible heat transfer (Bouskill *et al.*, 1998a).



A hydrophilic-hydrophobic blended fabric has been observed to cause the wicking of water from the inside layer (hydrophobic) to an outer layer (hydrophilic) causing accumulation of sweat on the outer layer and preventing evaporation of sweat from the skin and increasing skin temperature (Bakkevig and Nielsen, 1994). The condensation of water within a clothing layer causes a release of heat, increasing the temperature of the clothing and contributing nothing to the dissipation of body heat. Nevertheless, skin wettedness has been shown to be directly correlated with thermal comfort (Winslow *et al.*, 1939) and reduced moisture on the skin surface results in a greater perceived thermal comfort (Winslow *et al.*, 1937; Bakkevig and Nielsen, 1995).

It is these conflicting factors, which may benefit or impede athletic performance. In an attempt to counteract the effects of warm conditions, many sportswear manufacturers have developed technical weave polyester fabrics designed for moisture management, wicking sweat away from the surface of the skin, improving thermal comfort and delaying fatigue. The thermal resistance of polyester can be altered by reducing the amount of fibres packed within a given area of fabric (Yoon and Buckley, 1984). Examples of these generally available on the market are:

- Reebok Hydromove
- Adidas Climalite
- Nike Dri-Fit
- Coolmax
- Umbro Comformax
- Mizuno Icetouch

These claims have not been substantiated with comprehensive applied research particular to the soccer setting. The purpose of this study is to quantify the responses to soccer-specific exercise in a warm environment while comparing soccer training kit



incorporating traditional fabric with kit containing technical fabric. The findings of the previous study show the extra physiological demand of exercise in a warm environment with elevations in parameters such as core temperature, heart rate, skin blood flow and rating of perceived exertion. If clothing such as that described above can improve peripheral cooling during physical activity in a warm environment, then performance will be improved concomitantly.

If manufacturers' claims are true, technical clothing will initially improve thermal comfort by reducing skin wettedness. However, the removal of sweat from the surface of the skin immediately upon production will reduce evaporative cooling, elevating skin temperature and impacting upon core temperature. The sweat absorbed into the clothing will evaporate from the surface of the clothing and have no thermoregulatory or physiological benefit to the wearer. This will then cause an increase in sweat loss when wearing the new technical fabrics, which will be greater than when wearing traditional polyester fabrics. The lesser evaporative cooling will necessitate a greater sweat production in an attempt to compensate. The consequence of increased sweat production is dehydration and reduced blood volume. The conflicting demands of muscle blood flow requirements and peripheral blood flow requirements are further exacerbated as dehydration advances, inducing a greater heart rate, blood lactate concentration, prolactin concentration, and skin blood flow when wearing technical clothing compared to traditional clothing. Reduced peripheral cooling and increased core heat storage invoke a increased compensatory requirement of blood flow to the periphery, further intensifying the conflicts between blood distribution to active tissue and cutaneous vasculature.



The aim of this study is to determine the thermal and physiological demands of soccer specific intermittent exercise when wearing a new "technical" sweat wicking ensemble compared to a traditional ensemble.

## **7.2 RESEARCH HYPOTHESES**

Hypothesis 17: Technical clothing improves thermal comfort by wicking sweat away from the skin surface reducing wettedness. Therefore it is hypothesised that:

- a. Technical clothing reduces thermal perception closer to 'neutral' than when wearing the traditional fabric ensemble
- b. Technical clothing reduces the rating of perceived exertion compared to traditional clothing.

Hypothesis 18: Sweat production increases to compensate for reduced cooling, impacting on physiological and thermoregulatory responses. Therefore it is hypothesised that:

- a. Body mass loss increases when wearing the new technical clothing due to increased sweat production.
- b. Skin temperature is elevated when wearing the technical clothing, increasing in core temperature.
- c. Technical clothing induces a greater heart rate than traditional clothing.
- d. Technical clothing causes elevated blood lactate concentration compared to traditional clothing.
- e. Technical clothing invokes a greater prolactin concentration compared to traditional clothing.
- f. Skin blood flow is elevated when wearing the technical clothing ensemble compared to the traditional clothing ensemble.



### 7.3 METHODOLOGY

#### 7.3.1 Subjects

Experiments were conducted on six healthy male university students, who were moderately active and participated in soccer training a minimum of once a week. All subjects were considered to be non-acclimatised to any environmental extremes. The mean physical characteristics of the subjects were measured on the first visit to the laboratory and are shown in Table 7.1. All subjects were given written information concerning the practical details, nature, purpose, risks and procedures of the experiment and all freely volunteered for the study. Written informed consent was obtained from each of the participating individuals. The study was approved by the Human Ethics Committee at Liverpool John Moores University and conforms to all policy regarding the use of human subjects.

**Table 7.1.** Mean ( *s* ) subject physical characteristics (n = 6).

	Age (years)	Mass (kg)	Height (m)	BMI (kg m <sup>-2</sup> )	$\dot{V}O_{2\max}$ (ml kg <sup>-1</sup> min <sup>-1</sup> )	Surface Area (m <sup>2</sup> ) <sup>a</sup>	% Body Fat <sup>b</sup>
Mean	20.3	74.8	1.82	22.7	63.0	1.95	13.5
<i>s</i>	0.5	5.1	0.06	1.5	6.4	0.09	2.8
Range	20 – 21	67.9 – 83.3	1.75 – 1.89	20.9 – 24.3	56.9 – 70.1	1.83 – 2.10	10.2 – 16.8

<sup>a</sup> (Dubois and Dubois, 1916)

<sup>b</sup> (Durnin and Womersley, 1974)

#### 7.3.2 Exercise and Environmental Conditions

The experiments were conducted in an environmental chamber (RSM Air Conditioning, Liverpool, UK) with temperature and humidity levels controlled. Temperature control was set at 30°C with relative humidity at 45% for both visits to the laboratory.





Each participant visited the laboratory on three separate occasions, at least three days apart and at the same time of day to eliminate any circadian variation in performance or thermoregulatory response. An initial assessment of subjects'  $\dot{V}O_{2\text{ max}}$  was followed by three experimental test conditions. The subjects'  $\dot{V}O_{2\text{ max}}$  was recorded using a continuous incremental test on a motorised treadmill (Pulsar, HP Cosmos, Nussforf-Traunstein, Germany). Gas was analysed using a breath-by-breath mass spectrometer gas analysis system (Morgan Medical, Rainham, Kent, UK) with measurements calculated every 15 seconds. All gas volumes were corrected to STPD. Prior to the assessment of  $\dot{V}O_{2\text{ max}}$ , anthropometric measurements were taken in order to calculate body density, percentage body fat (Durnin and Womersley, 1974), body mass index ( $\text{BMI} = \text{kg m}^{-2}$ ) and surface area (Dubois and Dubois, 1916). The results are displayed in Table 7.1. Each subject then returned to the laboratory on two further occasions and was asked to perform 45 min of intermittent exercise in each of the two clothing treatments described below.

The intermittent protocol, detailed in Section 3.5, page 87, was conducted on a motorised treadmill (Pulsar, HP Cosmos, Nussforf-Traunstein, Germany) and represented the actions of outfield soccer players during match-play conditions. All subjects were familiarised with running on a motorised treadmill and the equipment used.

### 7.3.3 Procedures

On the day of each trial the subjects reported to the laboratory 30 minutes prior to the trial beginning. Participants wore one of two soccer training clothing ensembles (Clothing manufacturers information is contained in Appendix 7) in the two experimental sessions:



Clothing Ensembles	
<p><b>A – Traditional</b></p> <p>Running shoes (subjects own)</p> <p>Socks (Umbro <i>Comformax</i>)</p> <p>Underwear (subjects own)</p> <p>Shorts (Umbro, 100% polyester, traditional)</p> <p>T-Shirt (Umbro, 100% polyester, traditional)</p>	<p><b>B – Technical</b></p> <p>Running shoes (subjects own)</p> <p>Socks (Umbro <i>Comformax</i>)</p> <p>Underwear (subjects own)</p> <p>Shorts (Adidas, 100% polyester, "Climalite")</p> <p>T-Shirt (Reebok, 100% polyester, Hydromove")</p>
	

**Plate 7.1.** Illustration of clothing worn during the experimental trials.

Prior to testing, and upon completion, the subject weighed themselves nude. Following the initial weighing the participant inserted a rectal temperature probe to a depth of 10cm beyond the anal sphincter to allow continuous measurement of core temperature. The participant then rested in a supine position at which time the thermistors and laser Doppler probes were placed upon the skin with sterile surgical adhesive tape (Transpore, 3M, Michigan, USA). Skin blood flow (SkBF) of the chest, arm, thigh and shin was



measured using laser Doppler flowmetry (Periflux, Perimed UK Ltd.) and baseline skin temperature measurements were taken during 10 min of supine rest. Venous blood samples were taken immediately following the initial supine rest and immediately post-exercise for the analysis of energy metabolites [glucose, lactate, nonesterified fatty acids (NEFA) and prolactin] plasma osmolality (pOsm), and change in plasma volume ( $\Delta PV$ ) calculated from haematocrit and haemoglobin (Dill and Costill, 1974). All samples were assayed in duplicate.

#### 7.3.4 Measurements and Analysis

Heart rate, rectal temperature, mean skin temperature ( $\bar{T}_{sk}$ ) and mean body temperature ( $\bar{T}_b$ ) and environmental temperature were assessed throughout the exercise period and overall heat storage ( $S$ ) was assessed for each session using the equation of Burton (1935). All procedures are detailed in Chapter 3.

Arterialised capillary blood samples were taken in addition to the venous blood samples on two occasions: mid-test and 5 min post-test. Duplicate 50  $\mu l$  samples of arterialised capillary blood were immediately deproteinized in 100  $\mu l$  of 8 % perchloric acid, centrifuged, supernatant removed, placed into fresh tubes, frozen and then later analysed for lactate, glucose and non-esterified fatty acids (NEFA).

During the period of exercise participants were requested to give a rating of perceived exertion on a scale between 1 to 10 (Borg, 1970) shown in Table 3.2 and ratings of thermal comfort (Nielsen *et al.*, 1989) shown in Table 5.2.

One participant was unable to complete the exercise when wearing Ensemble B due to core temperature reaching and maintaining 39.5°C. The individual completed the



majority of the exercise, terminating activity at 30 min. The data from the participant are included in the analysis.

## **7.4 RESULTS**

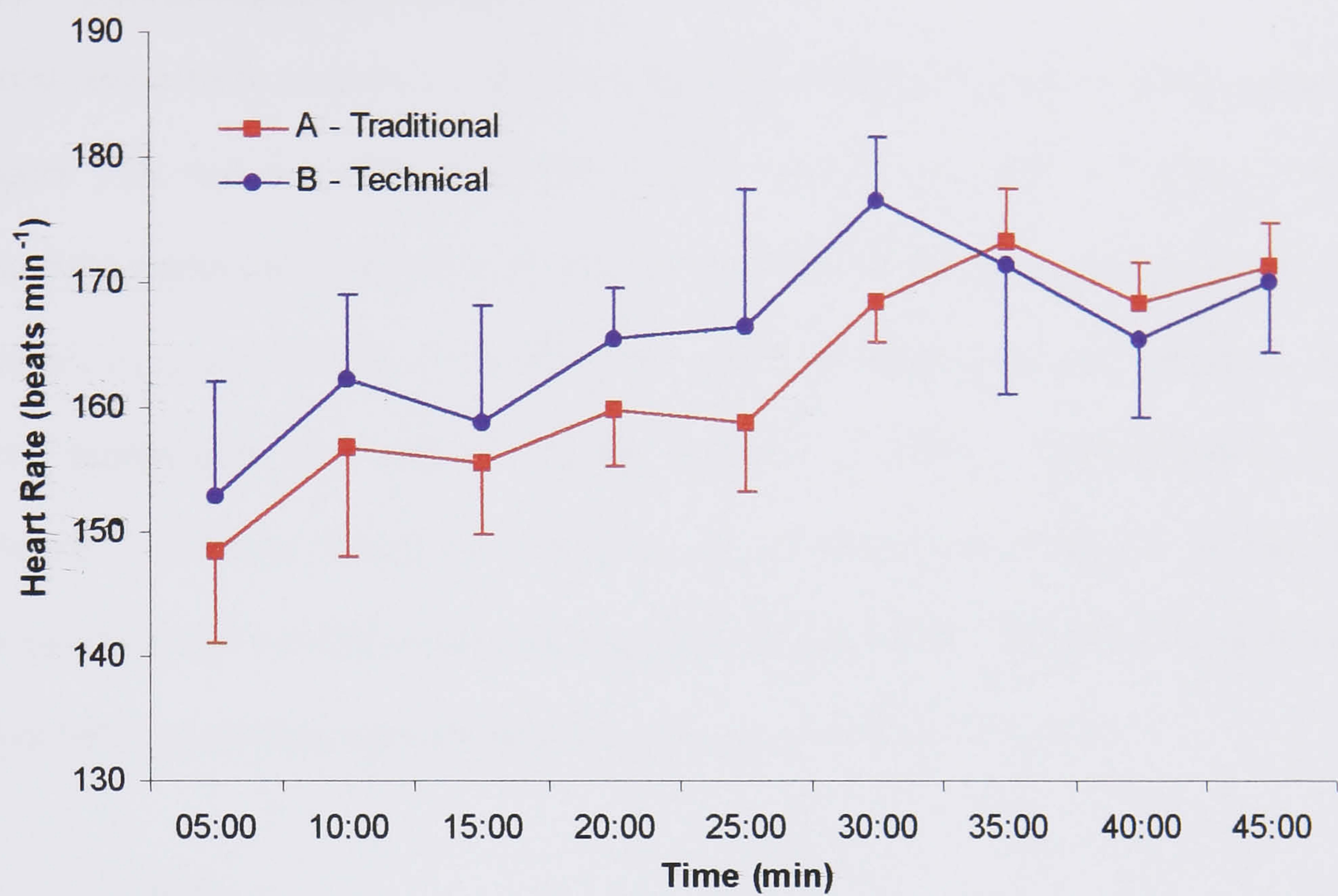
### **7.4.1 Environmental Conditions**

The ambient temperature was  $29.4 \pm 1.1^{\circ}\text{C}$ , relative humidity of  $40.0 \pm 3.1\%$  when exercising in traditional clothing ensemble A and  $28.5 \pm 1.1^{\circ}\text{C}$ , relative humidity of  $41.1 \pm 5.3\%$  when wearing technical clothing ensemble B.

### **7.4.2 Cardiorespiratory Responses**

Heart rates increased over the duration of exercise and Figure 7.1 shows the mean heart rate recorded at 15-s intervals during exercise in the two clothing conditions. The overall mean heart rates were similar ( $F_{1,5} = 0.434$ ,  $P = 0.539$ ) at  $162 \pm 10$  beats  $\text{min}^{-1}$  and  $166 \pm 10$  beats  $\text{min}^{-1}$  for the traditional (A) and technical (B) clothing trials respectively.





**Figure 7.1.** Mean heart rate during soccer specific exercise in clothing trial A (traditional) and clothing trial B (technical) at 30°C.

Both clothing conditions evoked similar increases in heart rate over the duration of the exercise (Table 7.2) and these increases were significant ( $F_{1,385, 6.927} = 9.722, P = 0.013$ ) although there was no interaction between clothing condition and time ( $F_{5,533, 27.665} = 0.785, P = 0.580$ ). Tukey's HSD post-hoc analysis identified that mean heart rates at 5, 10 and 15 min were each different to mean heart rates at 30, 35, 40 and 45 min.

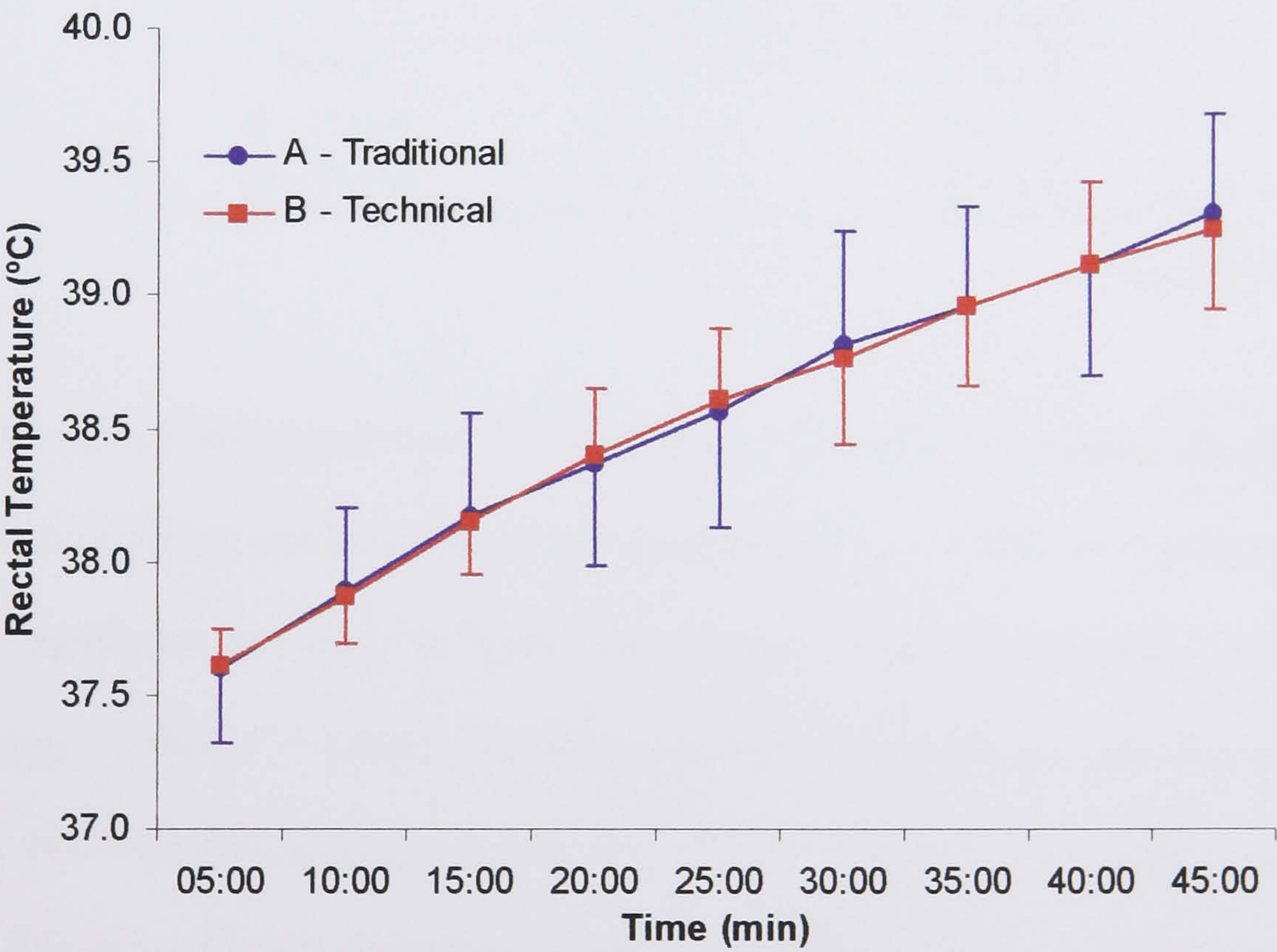
**Table 7.2.** Mean (s) heart rate values for total duration of exercise, first 22 min and last 22 min.

Beats min <sup>-1</sup>	A – Traditional	B – Technical
Overall	162.3 ± 9.7	165.5 ± 10.3
0 – 22 min	155.5 ± 7.8	160.5 ± 8.9
23 – 45 min	169.4 ± 5.8	171.1 ± 8.5



### 7.4.3 Thermoregulatory Responses

Rectal temperature recorded during exercise when wearing the two clothing ensembles (Figure 7.2) was not affected by the fabric types ( $F_{1,5} = 0.072$ ,  $P = 0.800$ ). Both ensembles responded similarly to the duration of exercise and increased significantly over time ( $F_{3,224, 16.119} = 76.292$ ,  $P = 0.000$ ) with significant differences occurring from mean rectal temperature at 5 min vs. 10 min upwards ( $P < 0.05$ ). Differences in rectal temperature between 35 min vs. 40 min, 35 min vs. 45 min and 40 min vs. 45 min were not significant ( $P > 0.05$ ), suggesting a possible plateau effect. There was no interaction effect between clothing type and time ( $F_{6,332, 31.609} = 1.719$ ,  $P = 0.124$ ).



**Figure 7.2.** Mean (*s*) rectal temperature (°C) during soccer specific exercise in two clothing conditions.

Overall mean weighted skin temperature ( $\bar{T}_{sk}$ ), shown in Figure 7.3, was not different between trials: Ensemble A  $35.3 \pm 0.6^{\circ}\text{C}$  and ensemble B  $34.8 \pm 0.6^{\circ}\text{C}$ . Although skin temperature was shown to increase over time ( $F_{4,207, 21.037} = 4.550$ ,  $P = 0.008$ ), Tukey's



HSD post-hoc tests showed that the significant differences were not particularly relevant, occurring only between time point 5 min vs. 25 min and 5 min vs. 40 min. There were no differences between clothing condition ( $F_{1,5} = 0.030$ ,  $P = 0.869$ ) or interaction between clothing and time ( $F_{5.013, 25.063} = 0.780$ ,  $P = 0.574$ ).

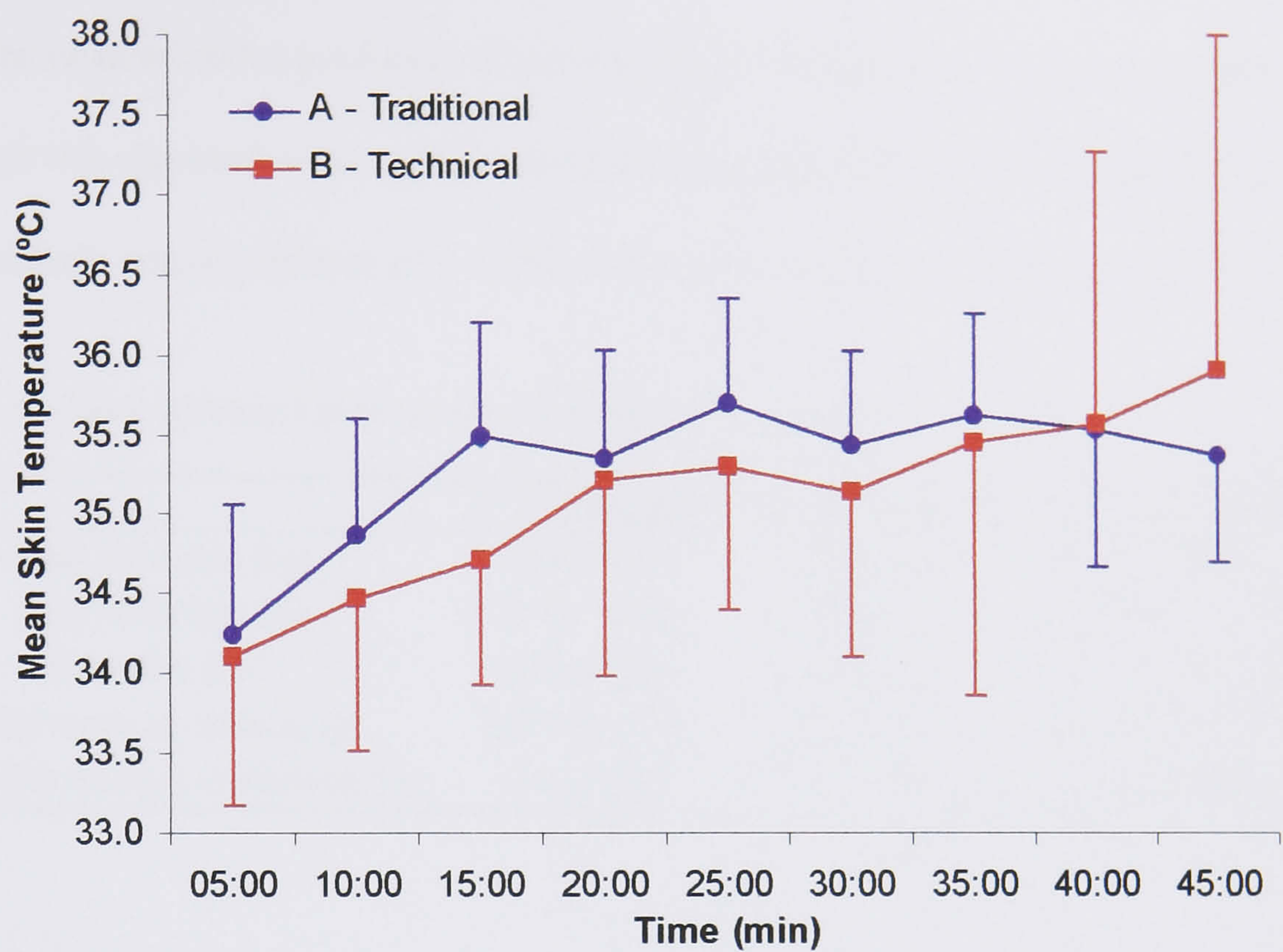
When wearing the traditional clothing ensemble (A)  $\bar{T}_{sk}$  appeared to stabilise following 15 min of exercise whereas the technical clothing ensemble (B) continued to evoke a rise in temperature.

**Table 7.3.** Mean ( $s$ ) weighted body temperature over total duration of exercise, first 22 min and last 22 min.

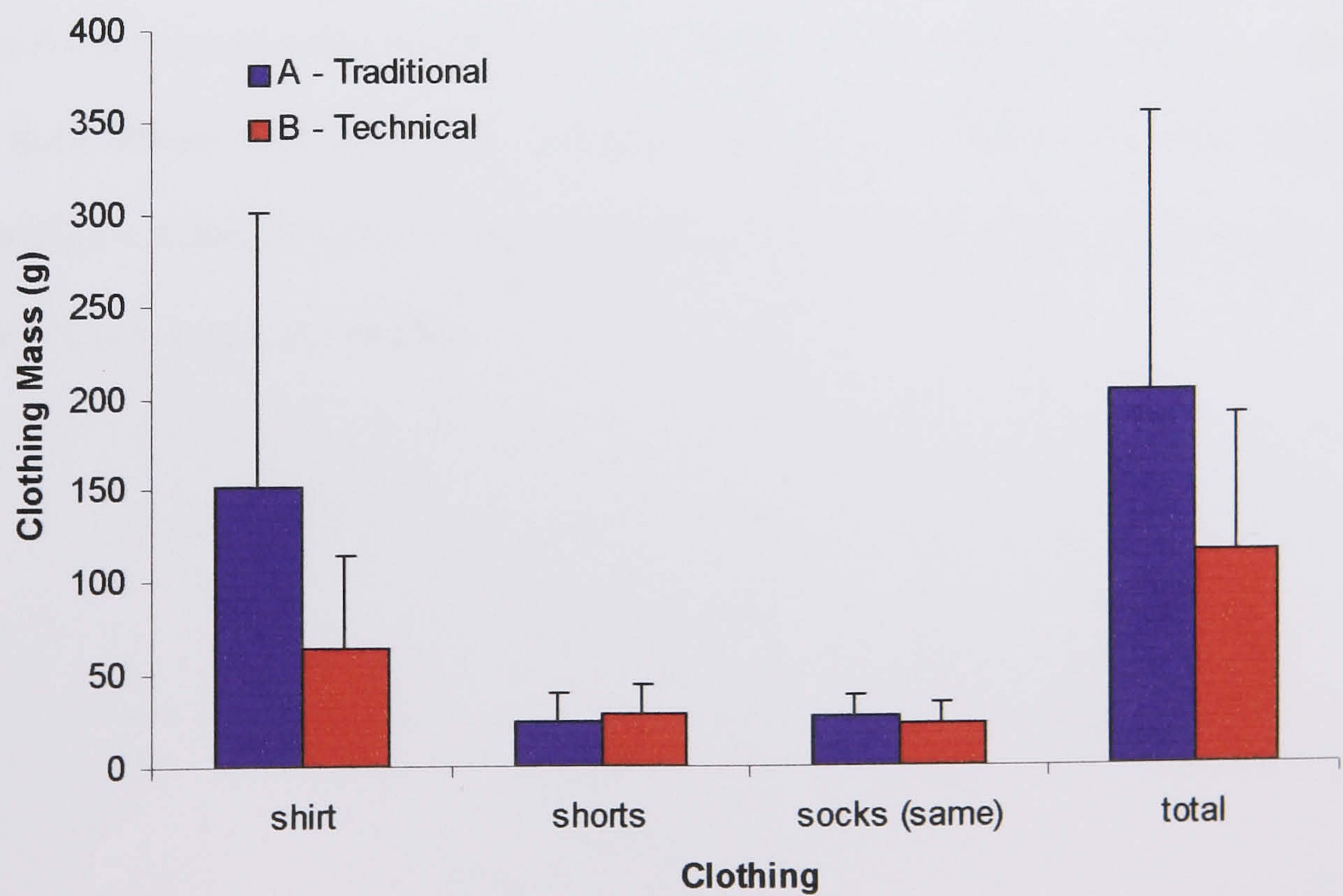
°C	A – Traditional	B – Technical
Overall	$37.4 \pm 1.3$	$37.2 \pm 0.8$
0 – 22 min	$36.6 \pm 1.2$	$36.9 \pm 0.5$
23 – 45 min	$38.3 \pm 0.4$	$37.5 \pm 1.0$

Weighted mean body temperature  $\bar{T}_b$  is displayed in Table 7.3. Again, the differences between the clothing conditions were not significant ( $F_{1,5} = 0.000$ ,  $P = 0.985$ ) but there was a significant increase in body temperature over the duration of exercise ( $F_{3.836, 19.182} = 3.663$ ,  $P = 0.023$ ). There was no interaction between the main effects of clothing and time ( $F_{2.031, 10.153} = 0.702$ ,  $P = 0.520$ ). Similarly, the differences in heat storage following 45 min of exercise were not significant ( $F_{1,5} = 1.074$ ,  $P = 0.347$ ) at  $137.5 \pm 134.8$  and  $78.3 \pm 13.2 \text{ W m}^{-2}$  when wearing A - Traditional and B - Technical ensembles respectively.





**Figure 7.3.** Mean (*s*) weighted skin temperature (°C) during soccer specific exercise in two clothing conditions.



**Figure 7.4.** Increase (mean, *s*) in clothing mass (g) following soccer specific exercise in two clothing conditions.



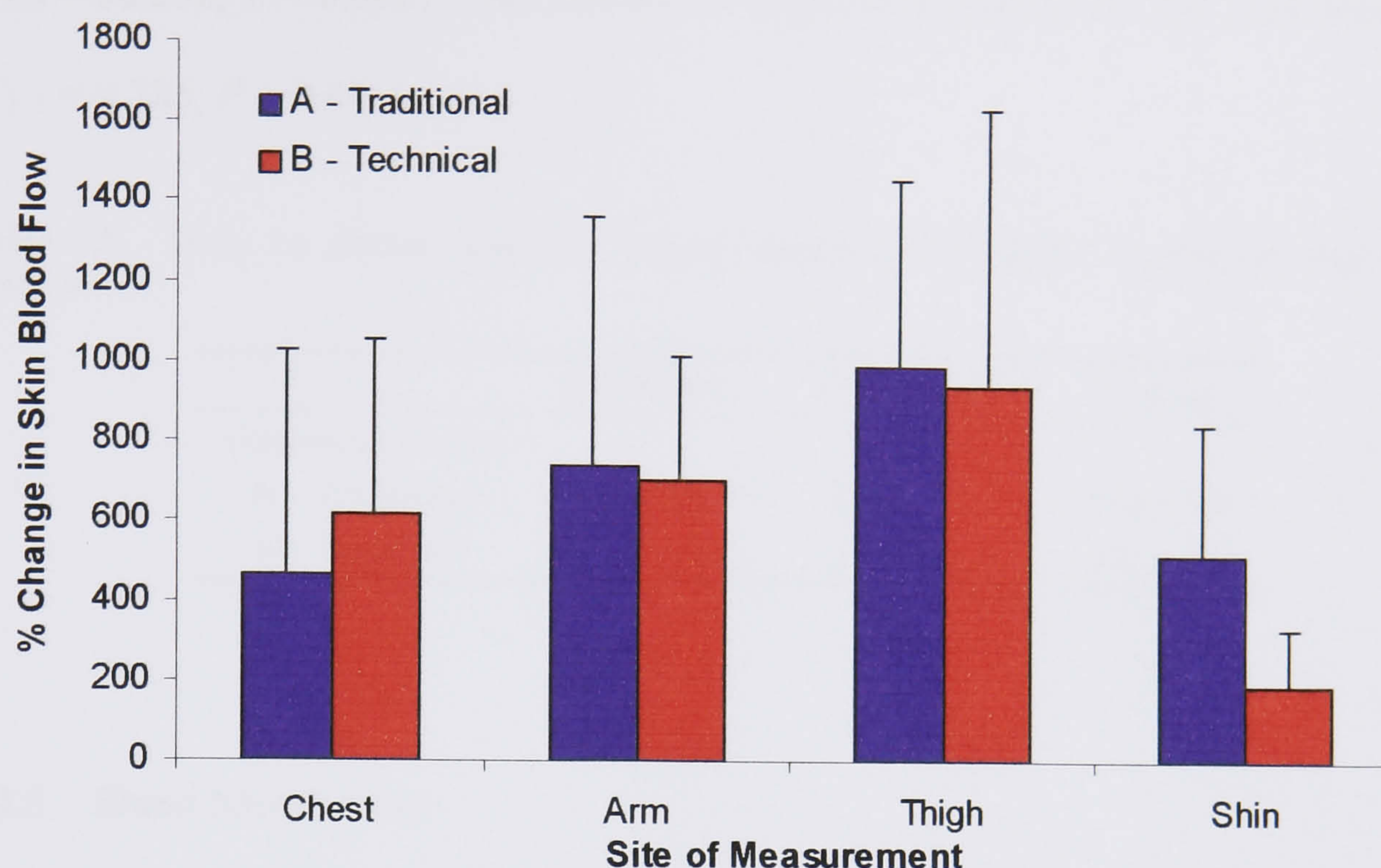
Subjects sweated more profusely when wearing the traditional clothing ensemble, although this elevated sweat production was not significant and the accumulation of sweat was similarly non-significant ( $P > 0.05$ ). This information is detailed in Table 7.4.

**Table 7.4.** Sweat losses and accumulation of sweat within clothing.

	A – Traditional	B – Technical	ANOVA Results
Body mass loss (kg)	$1.74 \pm 1.49$	$1.23 \pm 0.33$	$F_{1,5} = 1.076, P = 0.347$
Body mass loss (%)	$2.35 \pm 1.96$	$1.65 \pm 0.45$	$F_{1,5} = 0.974, P = 0.369$
Sweat rate ( $\text{l h}^{-1}$ )	$2.32 \pm 1.98$	$1.64 \pm 0.44$	$F_{1,5} = 0.973, P = 0.369$
Total sweat in clothing (g)	$203.8 \pm 151.8$	$115.5 \pm 75.6$	$F_{1,5} = 1.867, P = 0.230$
Sweat loss retained in clothing (%)	$15.9 \pm 17.1$	$9.2 \pm 4.13$	$F_{1,5} = 0.809, P = 0.410$

Increases in skin blood flow (Figure 7.5) were similar during exercise in both clothing conditions ( $F_{(1,5)} = 0.463, P = 0.527$ ). Overall differences in site were found to be significant ( $F_{(3,15)} = 4.137, P = 0.025$ ) and changes in skin blood flow from pre-exercise to post-exercise were also significant ( $F_{1,5} = 56.081, P = 0.001$ ). No interactions between the main effects were significant: clothing  $\times$  site ( $F_{3,15} = 1.081, P = 0.387$ ), clothing  $\times$  time ( $F_{1,5} = 0.304, P = 0.605$ ), site  $\times$  time ( $F_{3,15} = 1.529, P = 0.248$ ), and clothing  $\times$  site  $\times$  time ( $F_{3,15} = 1.421, P = 0.276$ ).





**Figure 7.5.** Change (*s*) in skin blood flow following soccer specific exercise in two clothing conditions.

Tukey's HSD post hoc tests confirmed that pre-exercise skin blood flow was significantly lower ( $P < 0.05$ ) than post-exercise skin blood flow. Tukey's tests also identified the differences in measurement site as both upper body sites of measurement resulting in a greater skin blood flow than the lower body sites ( $P < 0.05$ ). There were no differences between chest and arm or thigh and shin ( $P > 0.05$ ).

#### 7.4.4 Plasma Volume and Osmolality

Plasma volume decreased from pre-exercise to post-exercise by  $-9.86 \pm 2.09\%$  when wearing the traditional clothing and  $-6.70 \pm 2.39\%$  when wearing the technical clothing. The reduction in plasma volume when wearing ensemble A was significantly greater than the reduction in ensemble B ( $F_{1,5} = 6.770$ ,  $P = 0.048$ ). This result is also reflected in the greater increase in plasma osmolality during exercise in the traditional clothing (A) although this change was not significantly different from the technical trial ( $F_{1,5} = 0.082$ ,  $P = 0.786$ ). The increase in plasma osmolality following exercise was significant



( $F_{1,5} = 38.252$ ,  $P = 0.002$ ). No interaction effect of clothing trial and time was found ( $F_{1,5} = 0.786$ ,  $P = 0.416$ ).

**Table 7.5.** Mean ( $s$ ) plasma osmolality (mosm) during soccer specific exercise the two clothing conditions.

	Pre-exercise	Post-exercise	Change
<i>Osmolality (mosm)</i>			
A – Traditional	300.3 $\pm$ 6.2	311.4 $\pm$ 8.1	11.2 $\pm$ 8.6
B – Technical	301.7 $\pm$ 3.9	308.8 $\pm$ 4.4	7.2 $\pm$ 3.9

#### 7.4.5 Blood Metabolites

Plasma glucose increased from pre-exercise to post-exercise by approximately 8% for both clothing trials, although this increase was not significant ( $F_{1,5} = 2.391$ ,  $P = 0.183$ ). and similar for both trials ( $F_{1,5} = 0.109$ ,  $P = 0.755$ ). No interaction of clothing and time resulted ( $F_{1,5} = 0.062$ ,  $P = 0.813$ ). Plasma NEFA concentrations were significantly greater ( $P < 0.05$ ) in the traditional clothing (A) trial than the technical clothing trial (B) ( $F_{1,5} = 8.001$ ,  $P = 0.037$ ) and post exercise NEFA was greater ( $P < 0.05$ ) than pre exercise levels ( $F_{1,5} = 10.057$ ,  $P = 0.025$ ). An interaction of clothing and time is possible as final result was nearing significance ( $F_{1,5} = 5.445$ ,  $P = 0.067$ ) and Eta Squared of 52% suggests there may be a worthwhile effect present. The possible interaction is likely to be due to a much higher concentration of NEFA in trial A compared to trial B pre-exercise as well as post-exercise. Correction of NEFA and glucose for change in plasma volume did not effect the statistical results.

The response of plasma prolactin to the type of clothing worn is also shown in Table 7.6. There is no difference between the clothing conditions ( $F_{1,5} = 2.517$ ,  $P = 0.173$ ) although there is a general trend ( $P > 0.05$ ) for the levels of prolactin to increase over the duration



of exercise and exposure to heat ( $F_{1,5} = 5.110$ ,  $P = 0.073$ ). No interaction between clothing condition and time was found ( $F_{1,5} = 1.060$ ,  $P = 0.350$ ). When corrected for change in plasma volume the change in prolactin from pre-exercise to post-exercise was found to be significant ( $F_{1,5} = 15.876$ ,  $P = 0.010$ ).

**Table 7.6.** Glucose, NEFA and Prolactin concentrations (mean  $\pm$  s) pre and post exercise when wearing traditional (A) and technical (B) clothing ensembles.

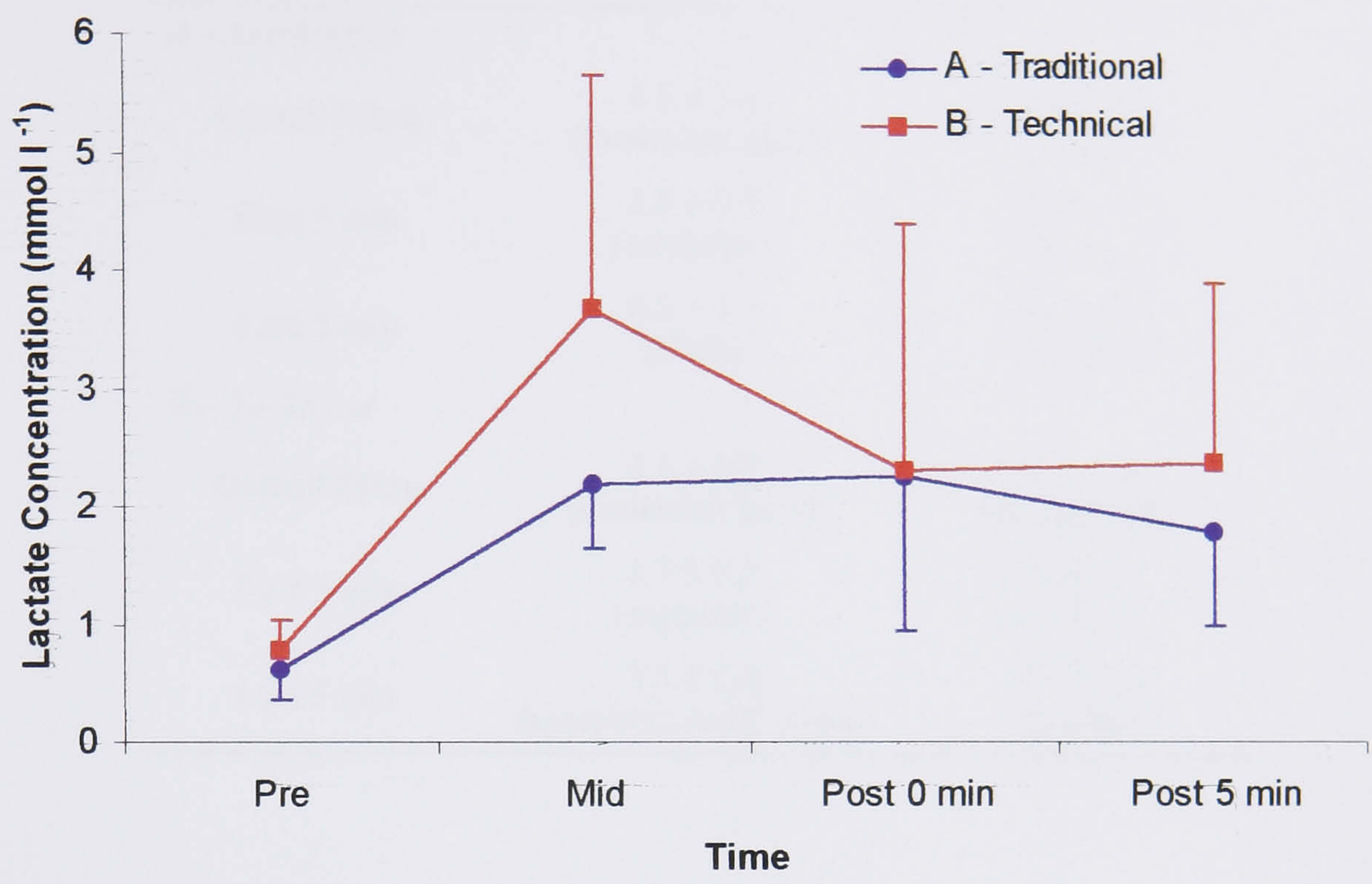
	Pre-Exercise	Post-Exercise	Change
<i>Plasma Glucose (mmol l<sup>-1</sup>)</i>			
A - Traditional	5.7 $\pm$ 1.5	6.0 $\pm$ 1.1	0.4 $\pm$ 0.6
B - Technical	5.5 $\pm$ 0.5	6.0 $\pm$ 1.0	0.5 $\pm$ 1.0
<i>Plasma NEFA (<math>\mu</math>mol l<sup>-1</sup>)</i>			
A - Traditional	714.0 $\pm$ 276.3	1284.6 $\pm$ 388.7	570.4 $\pm$ 428.6
B - Technical	292.4 $\pm$ 294.9	684.7 $\pm$ 584.9	392.3 $\pm$ 332.3
<i>Serum Prolactin (mIU l<sup>-1</sup>)</i>			
A - Traditional	215.0 $\pm$ 95.3	815.0 $\pm$ 754.8	600.0 $\pm$ 721.0
B - Technical	160.2 $\pm$ 32.1	629.7 $\pm$ 464.5	469.5 $\pm$ 447.1

Lactate concentration was analysed pre-exercise, mid-exercise, immediately post-exercise and 5 min post-exercise with the results illustrated in Figure 7.6. During exercise in trial B (technical clothing) there is a large increase in lactate concentration, which decreases immediately post exercise. This increase is not evident in trial A (traditional clothing).

At 5 min post-exercise the lactate concentration was still greater than pre-exercise levels.

ANOVA and Tukey's HSD identified a significant effect of time ( $F_{1,208, 4.833} = 11.013$ ,  $P = 0.020$ ) on lactate concentration where pre-exercise lactate concentration was significantly lower than mid-exercise concentration ( $P < 0.05$ ). There was no significant effect of clothing ( $F_{1, 4} = 2.181$ ,  $P = 0.214$ ) or any interactions between clothing treatment and time ( $F_{1,723, 6.893} = 2.149$ ,  $P = 0.189$ ).





**Figure 7.6.** Blood lactate concentration (mean  $\pm$  s) during soccer specific exercise (mmol l<sup>-1</sup>) in two clothing conditions.

**7.4.6 Psychophysical Ratings**

Overall mean ratings of perceived exertion for the entire exercise period, the first 5 min and the last 5 min are shown in Table 7.7. There were no differences between clothing trial ( $F_{1,5} = 0.596, P = 0.475$ ) although both conditions showed a significant increase in RPE over time ( $F_{2,237,11.183} = 15.868, P = 0.000$ ). There was no interaction between clothing and time ( $F_{1.840,9.200} = 0.416, P = 0.656$ ). Similar statistical findings resulted from analysis of thermal perception with no effect of clothing ( $F_{1,5} = 1.009, P = 0.361$ ), or clothing  $\times$  time ( $F_{8,40} = 0.660, P = 0.723$ ), but a significant effect of time ( $F_{8,40} = 64.893, P = 0.000$ ).



**Table 7.7.** Mean (*s*) psychophysical ratings during soccer specific exercise in two clothing conditions.

	RPE	Thermal Perception
<i>A – Traditional</i>		
Overall Mean	4.5 ± 1.5 (somewhat hard)	7.9 ± 1.1 (hot)
First 5 min	2.8 ± 0.8 (moderate)	6.3 ± 0.4 (warm)
Last 5 min	6.3 ± 1.5 (Hard)	9.0 ± 0.0 (very hot)
<i>B – Technical</i>		
Overall Mean	4.1 ± 2.0 (somewhat hard)	7.6 ± 1.0 (warm / hot)
First 5 min	2.7 ± 0.5 (moderate)	6.2 ± 0.4 (warm)
Last 5 min	5.5 ± 2.4 (somewhat hard / hard)	8.7 ± 0.5 (very hot)

## 7.5 DISCUSSION

The aim of this study was to examine the effects of a new technical clothing ensemble compared to a traditional clothing ensemble during soccer specific activity in a warm (~30°C) environment. The previous study presented in Chapter 6 demonstrated that exercise in a warm environment was negatively affected in a warm (30°C) environment compared to a neutral (20°C) and cool (10°C) environment. Exercise in the warm environment resulted in significantly ( $P < 0.05$ ) elevated physiological responses including core temperature, RPE, heart rate, skin blood flow, change in plasma volume and plasma osmolality. The manufacturers of the new technical clothing ensemble claimed the new fabrics used in this study would reduce thermal discomfort during activity and improve performance. The main finding of this study was that overall physiological response during intermittent soccer specific activity was not significantly ( $P > 0.05$ ) affected by the fabric type composing the apparel. Nevertheless, some possible



thermoregulatory and physiological benefits of the new technical clothing ensemble can be interpreted from the results, contrary to the expectations of the research hypotheses.

Similarities in rectal temperature between the two clothing conditions throughout the exercise period suggest that core temperature, as represented by rectal temperature in this study, was not affected by the clothing worn and therefore there were no differences in thermal load. Rectal temperature did not stabilise in either clothing trial. If the manufacturers' claims for the technical fabrics had been validated, core temperature when wearing ensemble B (technical) would have been lower and some stabilisation may have occurred similar to the response reported for soccer specific intermittent activity in a neutral ( $\sim 20^{\circ}\text{C}$ ) environment in the previous chapter (Figure 6.2).

In contrast to the similarities in rectal temperature, heart rate was fractionally higher ( $P > 0.05$ ) when wearing the traditional clothing ensemble. As reported in the previous chapter, heart rate progressively rose throughout the activity period in the warm environment due to the phenomenon known as 'cardiovascular drift' (Boutcher *et al.*, 1995; Coyle, 1998). Change in skin blood flow was fractionally greater ( $P > 0.05$ ) when wearing the traditional ensemble in three of the four sites measured (Figure 7.5). This tentatively suggests that redistribution of blood to the skin contributed to a reduction in central blood volume and hence a rise in heart rate in order to maintain cardiac output. The mean heart rate values of the first half of the exercise period and the second half of the exercise period separately (Table 7.2) illustrate the gradually increasing heart rate to counteract a lower stroke volume.

Skin temperature was  $0.5^{\circ}\text{C}$  higher in trial A (traditional) than in trial B (technical) although this difference was not considered significant ( $P > 0.05$ ). Nevertheless, this



slight elevation may impact upon thermal comfort and the slightly ( $P > 0.05$ ) elevated thermal comfort rating and rating of perceived exertion (Table 7.7) when wearing the traditional ensemble would support this suggestion.

Mean body temperature ( $\bar{T}_b$ ) is a function of core temperature and skin temperature ( $\bar{T}_{sk}$ ) and results were similar for both clothing conditions at approximately 37°C overall. These results support the conclusion that there was no difference in whole-body thermal strain created by the different fabrics in the two clothing ensembles. Interestingly, the relative value of heat storage, calculated from  $\bar{T}_b$  and body surface area, was slightly elevated ( $P > 0.05$ ) when wearing ensemble A compared to ensemble B, signifying that the traditional clothing ensemble may have posed a greater thermal demand. Additional measures that may corroborate this suggestion are the slightly, although not significantly ( $P > 0.05$ ), elevated mean weighted skin temperature (Figure 7.3), increased sweat production (Table 7.4), increased post-exercise skin blood flow (Figure 7.5), greater plasma volume reduction (Table 7.5) and increased serum prolactin (Table 7.6).

The absorptive properties of a material have an effect on physiological sweating mechanisms (Tokura and Midorkikawa-Tsurutani, 1985; Kakitsuba *et al.*, 1988). The process of evaporation and heat dissipation through clothing is dependent upon several elements. These factors include physical properties of the clothing, design of the clothing (McCullough *et al.*, 1983), clothing fit (Bouskill *et al.*, 1998b), body movement and activity (Nielsen *et al.*, 1985), air velocity (Bouskill *et al.*, 1998a), air temperature and air humidity (Kakitsuba *et al.*, 1988). Insulation of a clothing garment is mainly determined by the thickness of the material and trapped air (Bakkevig and Nielsen, 1995). To allow sweat and heated air to escape to the surrounding ambient air, the outer clothing layer



must be open to the environment allowing ventilation to remove and dissipate heat to cool the body. Sweat parameters measured in this study are detailed in Table 7.4. Both body mass loss and sweat accumulation within clothing were not significantly different ( $P > 0.05$ ), although, sweat loss and sweat accumulation were consistently lower when wearing the technical clothing ensemble compared to the traditional ensemble. This is in agreement to the manufacturers' claim.

Sweat may be transported through the technical fabric to the clothing surface during this process the vapour may condense within the fabric. When water vapour condenses the latent heat is liberated and the temperature of the clothing increases (Bakkevig and Nielsen, 1994). This heat may be dissipated to the ambient environment, but this is unlikely to have any effect on heat loss from the skin (Bakkevig and Nielsen, 1994).

Skin blood flow usually changes in combination with sweat production and skin temperature ( $\bar{T}_{sk}$ ). This effect is found in all sites apart from the chest area (Figure 7.5) where skin blood flow is higher during trial B (technical clothing) compared to trial A (traditional clothing). A significant effect of site was shown to be due to more elevated skin blood flow post-exercise in the upper body compared to the lower body. It is well reported that the human body surface is non-uniform with regard to skin blood flow, sweating and characteristics of the skin (Day, 1967)

The clothing ensembles were similar in all but the weave of the fabric. Similarities in overall thermal load may have been due to a similar ventilation index (Bouskill *et al.*, 1998a); consequently the insulation and evaporative resistance of the ensembles may have been similar. The pumping effect of clothing movement has previously been described as contributory to more efficient cooling compared to an unclothed trial in the same



conditions (Candas and Hoeft, 1995). The fit of the two clothing ensembles was also similar and the looseness of the technical ensemble may have negated the possible benefits of the fabrics (Bouskill *et al.*, 1998b). Even so, a study examining the effects of skin-tight, vapour permeable fabrics illustrated that excessive amounts of sweat were retained and time to exhaustion was reduced during exercise at  $\sim 80\% \dot{V}O_{2\max}$  (Brownlie *et al.*, 1987). The absorptive properties of a material may alter the sweating response of the skin (Tokura and Midorkikawa-Tsurutani, 1985; Kakitsuba *et al.*, 1988).

Plasma volume and osmolality are reliable indicators of hydration status (Jimenez *et al.*, 1999) and in this study there was a significantly ( $P < 0.05$ ) elevated increase in plasma volume and slightly ( $P > 0.05$ ) increased change in plasma osmolality during trial A (traditional), suggesting that the thermal demand and level of dehydration are greater when wearing the traditional apparel. Dehydration impacts upon many thermoregulatory mechanisms; an immediate consequence is the effect on central blood volume. Decreased blood volume results in a lower stroke volume, which is compensated for by elevated heart rate to maintain cardiac output to supply active muscle and skin vasculature with the required blood. This effect has been termed the "dehydration induced cardiovascular drift" by Coyle (1998). Combined with the cardiovascular drift already associated with demands for cutaneous cooling in a hot environment, dehydration induced cardiovascular drift may have serious consequences for performance in a warm environment (González-Alonso *et al.*, 1997).

Virtually no differences in plasma glucose concentration resulted from the two clothing trials. Pre-exercise values were very similar and post-exercise measurements were identical (Table 7.6) suggesting no differences in glycogenolysis supplying muscle energy



requirements. The measurements of lactate and NEFA show increased concentrations post-exercise during clothing trial A (traditional). These findings are puzzling as increased NEFA would suggest increased fat utilisation, usually due to low activity exercise while increased lactate suggests a higher exercise intensity as increased use of glycogen from the liver and muscle stores increases the production of the by-product, lactate.

The relationship of prolactin with thermal stress has been shown in the previous study (page 183) and hence any increased concentration of serum prolactin would suggest that a greater thermal demand was present (Mills and Robertshaw, 1981). As for many of the other physiological variables in this study, differences between clothing trials were not significantly different ( $P > 0.05$ ).

Psychological strain was examined using the subjective scales of RPE (Borg, 1982) and a thermal comfort scale (Nielsen *et al.*, 1989). In agreement with the apparel manufacturers' claims, a lower RPE and a thermal perception closer to neutral resulted from exercise in the technical clothing ensemble (B), although these results were not significantly different ( $P > 0.05$ ) from the traditional clothing trial (A). The strong relationship between skin wettedness and thermal comfort (Winslow *et al.*, 1937; Winslow *et al.*, 1939; Nielsen and Endrusick, 1990) suggests that a sweat wicking fabric will considerably improve perceived thermal comfort and possibly overall rating of perceived exertion. Previous work using the identical thermal sensation scale employed in this study (Bakkevig and Nielsen, 1995) measured skin wettedness and the total evaporation of sweat. Thermal sensation on the 1-9 scale mimicked the % of wettedness on the skin surface, further signifying the relationship between skin wettedness and



thermal comfort. Rectal temperature and mean skin temperature in the study by Bakkevig and Nielsen (1995) also showed a relationship with thermal comfort. Even when sweat is evaporated as soon as it is formed, there are marked increases in discomfort with increasing rate of sweat production (Bakkevig and Nielsen, 1995). The slightly lower sweat rate when wearing the technical clothing (Table 7.4) corroborates the relationship between reduced sweat production and the perception of thermal comfort.

The slight effects of the fabric composition is in agreement with findings of previous research which postulates that fabric thickness and the accumulation of sweat within the garment determines thermoregulatory and thermal comfort and not the fibre type (Bakkevig and Nielsen, 1995). The fibre types of the clothing in this study were the same material (100% polyester) but thickness and weave are different causing dissimilar sweat accumulation and hence different thermal characteristics.

## **7.6 CONCLUSION**

The thermoregulatory and physiological demands generated when exercising in a warm environment have ramifications for a soccer player exercising in an unfamiliar climate. Environmental heat may increase demands on heat loss mechanisms beyond an acceptable level and the use of technical fabrics such as those used in this study may give some slight benefits to the soccer player in enhancing heat dissipation. Analysis revealed that many differences in physiological parameters between traditional and technical clothing ensembles were not significant ( $P > 0.05$ ). Therefore, wearing technical fabric clothing gives no particular benefit over a traditional fabric ensemble.



## CHAPTER 8. SYNTHESIS OF FINDINGS



## 8. SYNTHESIS OF FINDINGS

*The aim of this section is to integrate the results of the experimental work contained within this thesis. The separate studies will be discussed together regarding the physiological and metabolic demands of clothing and environmental conditions with special reference to soccer specific intermittent exercise. The original hypotheses and aims of the thesis will be reviewed.*

### 8.1 REALISATION OF AIMS

The experimental chapters of this thesis (Chapters 4 to 7) have fulfilled the aims stated in Chapter 1. The effects of exercise mode (intermittent vs. continuous) were found to impact significantly upon the temperature of the feet (Aim 1). Increased skin temperature of the foot during the soccer specific activity may have implications for thermal comfort of the soccer player.

The effects of exercise and soccer equipment on the thermal responses of the feet were established by means of laboratory simulation of soccer specific intermittent exercise when wearing different socks and footwear (Aim 2). Soccer footwear does not have a significantly detrimental effect on localised thermal responses and overall performance compared with training shoes. Similarly, sock materials do not significantly affect thermal or physiological responses.

The effects of exercise and soccer equipment on the thermal responses of the hands were established by a laboratory simulation of goalkeeper specific intermittent exercise when wearing different goalkeeping gloves (Aim 3). The particular specification of PCM



evaluated encouraged heat gain rather than heat loss and was therefore inappropriate to enhance thermal comfort in this setting. Further material development is necessary to negate the problems of moisture build-up and heat gain within the glove microenvironment.

The effects of clothing layers on soccer specific intermittent exercise were evaluated in a controlled environmental chamber (Aim 4). A waterproof impermeable soccer-training top in addition to T-shirt and shorts was investigated in order to determine the effects of clothing layers on the physiological responses during simulated soccer-specific intermittent exercise on a motorised treadmill. The training top was observed to cause no substantial physiological effect compared to the same clothing ensemble without the training top.

Soccer activity was simulated on a treadmill in a neutral (20°C), warm (30°C) and cool (10°C) environments (Aim 5). It was demonstrated, for the first time, that the physiological, metabolic and thermoregulatory responses to soccer-specific intermittent exercise are dependent upon environmental temperature with performance negatively affected in a warm environment.

The physiological responses of the whole-body to technical soccer training garments was assessed during soccer specific intermittent exercise on a motorised treadmill in a controlled climatic chamber (Aim 6). No significant differences were found between technical fabrics and more traditional fabrics and hence the conclusion is that the use of technical fabrics has no physiological benefit during soccer activity in a warm environment.



## 8.2 *GENERAL DISCUSSION AND RECOMMENDATIONS*

The general aim of the thesis was to define the thermoregulatory responses during soccer specific intermittent exercise with special reference to the effects of clothing and environment. The analysis of the demands of soccer in different environmental and clothing conditions was achieved by the use of laboratory based experimentation. Laboratory simulations of soccer specific activity replicated soccer match-play as closely and as practically possible in a laboratory setting.

Chapter 4 of the experimental work was directed towards investigating the effects of exercise and clothing on peripheral thermoregulation. The results of the three studies presented in Chapter 4 indicated increases in clothed foot and hand skin temperature greater than increases in mean skin temperature ( $\bar{T}_{sk}$ ), demonstrating the localised nature of the thermal demands when wearing footwear and gloves.

The first study presented in Chapter 4 aimed to investigate the effects of intermittent and steady state activity on the thermal responses of the whole-body and the feet. The avenues for heat loss when wearing footwear are only by means of conduction through the soles into the ground, convection and radiation from the surfaces, convection from the openings at the ankles and lacing area, and evaporation through the material and openings. Circulation of air around the foot is likely to be insufficient to affect adequate heat loss resulting in elevated foot skin temperature when wearing footwear and a possible consequent whole-body thermal strain. Two groups of individuals performed 20 min of either steady-state exercise or soccer-specific intermittent exercise on a motorised treadmill. The findings indicated that the foot maintains an altered thermoregulatory response not evident elsewhere on the human body. Intermittent



exercise compared to continuous exercise induced elevated foot skin temperature of a greater magnitude. The increases in foot skin temperature were also in comparison with a relatively unchanged mean skin temperature ( $\bar{T}_{sk}$ ). The finding of a greater localised thermal demand during intermittent exercise compared to continuous exercise supports previous work, which reported a greater whole-body thermal demand from intermittent activity compared to steady state activity (Cable and Bullock, 1995).

The second of the three studies presented in Chapter 4 investigated the effects of different footwear on localised and whole-body responses during intermittent soccer specific activity. The first study had shown that localised thermal demands were higher during soccer specific intermittent activity, and the second study examined these demands when wearing soccer footwear. Kawabata and Tokura (1993) reported that different running shoes can invoke not only different local skin temperatures but also changes in whole-body responses such as core temperature and heart rate. Nevertheless, others found no effects of different running shoes on any physiological parameters (Lees and Thornley, 1990). The footwear study in this thesis aimed to quantify physiological responses to specific conditions of soccer boots or training shoes and soccer socks during simulated soccer activity. Results showed that there were differences between different types of sock and different types of shoe, but these differences were not statistically significant ( $P > 0.05$ ). Slight elevations in heart rate and core temperature were observed when wearing soccer boots compared to training shoes and the same boots with *Metcradle* insoles. It is possible that the *Metcradle* insoles are efficient at reducing impact upon footfall, reducing the friction, which generates heat (Lees and Thornley, 1990).



The third study presented in Chapter 4 quantified the thermal demands on the hands when wearing soccer goalkeeping gloves during simulated soccer goalkeeper activity. Work of this nature had, to our knowledge, not previously been performed and the findings were novel.

The investigation of the effects of soccer clothing and equipment on thermoregulation during soccer activity is important from the viewpoint of player comfort and performance. In the game of soccer, any advantage, no matter how small, may make the difference between winning and losing at the elite level where comfort and performance capacity of a player are extremely important. The results presented in Chapter 4 are interesting as they suggest that soccer clothing and equipment worn on the extremities do not pose any significant risks of thermal injury in a neutral environment as there are no changes in central temperature. Nevertheless, these studies do show that the peripheral temperature response is determined by both the exercise mode (i.e. steady state vs. intermittent) and to a certain extent the material used in socks and gloves. Needless to say, the physiological responses to such clothing and equipment may be considerably different in a hot or cold climate. Further work in the area of sports clothing and equipment should concentrate on the effects of adverse environmental conditions, as this is of particular interest when elite soccer players travel to international competition where the climate is somewhat different from the temperate climate of the United Kingdom.

Chapters 5, 6 and 7 aimed to investigate the effects of soccer clothing and environment on thermoregulation during soccer specific intermittent exercise. To our knowledge this is the first time the specific viewpoint of simulated soccer activity has been taken when evaluating the effects of both clothing and environmental conditions.



Soccer players often wear a rainproof training jacket during training (Plate 5.1). The effect of wearing this jacket was examined in Chapter 5. The addition of such an impermeable layer was expected to increase the thermal demand. Although some increases in parameters including mean skin temperature ( $\bar{T}_{sk}$ ), heart rate, RPE, perception of thermal comfort and sweat production, suggest that the extra clothing layer is provoking a greater thermal strain, these differences were slight and not considered significant ( $P > 0.05$ ). This finding may seem unusual considering the greater insulation offered by multiple layers. However, Bouskill (1998a; 1998b; 1999) and Havenith (1990a; 1990b; 1999) have shown that the intrinsic insulation of clothing is not necessarily the resultant insulation. Air movement within clothing layers and air movement into clothing layers through openings allow for heat exchange, effectively reducing the effective insulation of the ensemble. Increasing activity, increases the rate of air exchange in all clothing layers and even the slightest movements induced by breathing causes increased air exchange compared to a completely still state (Bouskill, 1999). Nevertheless, should the same clothing ensemble examined in Chapter 5 be worn in a warmer climate, the additional thermal strain may then become significant. Additionally, wearing the ensemble in colder conditions, which is more probable considering the use of the jacket is intended for colder weather rain protection, the jacket may not be suitable in preventing overcooling. Periods of sprinting during soccer play are often followed by recovery periods of static pauses or low intensity activity. It is during these latent periods that excessive levels of heat loss may occur.

To confirm or reject the observations that there is no significant additional thermal load when wearing the training jacket, the experiment outlined in Chapter 5 should be repeated in different environmental conditions. In particular, evaluation of the ensemble in a warm



environment should establish if the slight thermal load would become a significant risk to thermal injury in less favourable environmental conditions. Techniques of analysis of clothing ventilation (Bouskill, 1999) may also be employed to give biophysical data concerning the effects of movement and activity level on the ventilation characteristics of the multi-layer ensemble.

It is well known that endurance performance and physiological responses are affected by environmental conditions. Whilst some studies have examined the responses to intermittent exercise in the heat (Morris *et al.*, 1998), no studies have fully examined the effect of heat and cold on soccer-specific intermittent exercise. This thesis has shown, for the first time, that the physiological response to soccer activity is negatively affected in a warm (30°C) environment compared to a neutral (20°C) environment, while a cool (10°C) environment appears to provide optimal conditions for performance capacity in this particular study. Observations of heart rate, core temperature, skin temperature, skin blood flow, change in plasma volume, plasma osmolality, sweat production, RPE and lactate, all showed significant increases in a hot environment and generally the least changes when in a cool environment. Similar trends have been observed by Galloway and Maughan (1997) during endurance exercise of the same overall relative intensity as that reported for soccer match-play (70%  $\dot{V}O_{2\max}$ ), (Reilly, 1990).

The novel finding of a greater change in prolactin concentration during exercise in a warm environment compared to the change in prolactin during exercise in the neutral and cool environments confirm recent reports of such a link to thermal stress (Falk *et al.*, 1991) and studies that combine the measurement of core temperature and measurement of prolactin show a distinct relationship (Mills and Robertshaw, 1981). Another observation



was that as core temperature increased, prolactin concentration increased which suggests that there is a strong relationship between the two variables. It is interesting to note that the one individual that struggled to complete the hot trial in the study presented in Chapter 6 and failed to complete the hot trial in Chapter 7, presented with the greatest post-exercise prolactin concentrations [ $2240 \text{ mIU l}^{-1}$  (Chapter 6) and  $1519 \text{ mIU l}^{-1}$  (Chapter 7)]. However, core temperature at the end of exercise in neutral and cool conditions were almost identical at  $38.3 \pm 0.7^{\circ}\text{C}$  and  $38.4 \pm 0.3^{\circ}\text{C}$ , but prolactin concentration post-exercise was much lower in the cool condition. The divergent response to neutral and cool conditions has not been identified in such detail in the literature, but there are reports of prolactin inhibition in cool conditions (Mills and Robertshaw, 1981; Brisson *et al.*, 1989).

Central fatigue has been linked with increases in prolactin concentration (Blomstrand *et al.*, 1988; Davis and Bailey, 1997). Exercise at core temperature greater than  $38^{\circ}\text{C}$  has been reported to reduce central drive for motor performance contributing to onset of fatigue (Falk *et al.*, 1991). The resulting adverse effect on the central nervous system (Nielsen *et al.*, 1990) has been related to central serotonergic (5-hydroxytryptamine) activity with increased prolactin concentration as a marker of that central fatigue (Brisson *et al.*, 1986; Blomstrand *et al.*, 1988; Laatikainen *et al.*, 1988; Melin *et al.*, 1988; Davis and Bailey, 1997; Strachan and Maughan, 1999).

Skin blood flow has previously been shown to plateau at  $38^{\circ}\text{C}$  (Bregelmann *et al.*, 1977), although this is not apparent in the study presented in Chapter 6 as both neutral and cool conditions show similar end core temperatures at around  $38^{\circ}\text{C}$  but divergent post-exercise skin blood flow, as well as divergent prolactin response. Indeed, post-exercise



concentrations of prolactin (González-Alonso *et al.*, 1999) and post-exercise increase of skin blood flow were the most strongly correlated parameters measured, suggesting that they are related in some way. One intriguing possibility is that large increases in skin blood flow decreases central blood volume and threatens blood pressure regulation. It would follow that, in an attempt to avoid this scenario, central serotonergic mechanisms are evoked to cause fatigue. The mechanisms of prolactin release are unclear and further work should concentrate on determining the thermoregulatory or physiological factors that contribute to prolactin release. One such study would be to clamp skin temperature by means of a water perfused suit. Exercise at the same absolute intensity increases core temperature by the same level as core temperature is related to the metabolic rate (Noakes *et al.*, 1991). If skin temperature is clamped and core temperature changed by exercising at different levels of absolute work-load, the results should determine if skin blood flow or core temperature is the determining factor for the release of prolactin.

Given that exercise in the heat induces greater physiological, metabolic and thermal strain, in such an environment it would be extremely useful to accelerate heat loss. The standard clothing worn for soccer match-play takes the form of a T-shirt and shorts ensemble (see page 172 for a typical example). The design and fit of the clothing is dictated by tradition and convention and has remained relatively constant over the years. The recent introduction of technical "moisture management" fabrics for use in sports apparel has intended to give an athlete, including soccer players, performance advantages by improving both thermal comfort and heat dissipation (see Appendix 7 for manufacturers marketing literature). In the final study in this thesis (Chapter 7) it was observed that the greater thermoregulatory and physiological demands caused by exercise



in a warm environment are not significantly reduced by wearing soccer apparel comprised of technical fabrics.

Field testing should be regarded as the next stage in the evaluation of clothing effects on thermoregulation. The integration of laboratory investigations with field evaluation will provide complete understanding of the consequences of clothing and environment in a realistic setting. Simulation of soccer match-play in the laboratory setting is limited as soccer manoeuvres such as tackling, dribbling the ball, sideways and backwards movements, and interaction with other players are not possible on a treadmill. Field testing would enable inclusion of all these activities allowing an accurate evaluation of clothing during actual soccer match-play.

Physiological parameters recorded in Chapter 6 were significantly different between environmental conditions ( $P < 0.05$ ). However, the effect of the cool environment was not as physiologically demanding as expected. It is evident that more research on the topic of exercise in a mild cold environment is desirable. Further research could also extend the study presented in Chapter 6 into lower environmental temperatures. The evaluation of soccer specific intermittent exercise in temperatures below 10°C would be beneficial as would the determination of physiological demands over a wider range of temperatures. The consequences of environment on soccer match-play performance parameters such as power and strength have not been determined immediately following match-play and for the days following match-play. Does soccer in a hot environment diminish performance longer post-match than exercise in a neutral environment? Does playing soccer activity in a cold environment diminish performance for longer post-match than exercise in a neutral environment? These questions are relevant to elite soccer



players who often play important matches with only a day interval in between. Training demands are also high and coaches should be aware of the performance implications of training the day before an important match.

Evaluation of soccer activity vs. steady state exercise of the same overall work-load in cold and warm environments would be valuable to conclusively determine if physiological demands are elevated during soccer activity as previously suggested in neutral environmental conditions (Cable and Bullock, 1995). Additionally, this study should be expanded to examine an entire 90-min of simulated match-play in order to quantify more accurately the demands of soccer match-play.

### **8.3 CONCLUSIONS**

This aims set out in Chapter 1 of this thesis have been fulfilled, resulting in the demonstration of the effects of clothing and environment during soccer-specific intermittent activity.

The peripheral temperature responses reported in this thesis have a significant effect upon localised thermoregulation without altering whole-body thermoregulation. Similarly, the choice of clothing materials for the whole-body do not significantly affect physiological responses. The combination of the studies examining whole-body thermoregulation suggest that the clothing microenvironment is not altered by wearing different clothing ensembles and hence time to fatigue would not be affected. If differences in clothing microenvironment existed, differences in physiological responses would have resulted in a similar way to responses observed when exercising in different ambient temperatures.



The increased thermoregulatory and physiological demands when performing soccer-specific intermittent activity in a warm environment (30°C) suggest that a soccer game in such an environment will cause conditions of uncompensable heat stress and fatigue before the completion of the match at 90-min.

It may be that further material and fabric development may address the problems of reduced heat loss and moisture build-up when wearing soccer type clothing and soccer equipment, however, the current available sportswear materials are not beneficial in the settings for which they have been designed.

Therefore, the combined results within this thesis implicate suggest an elite soccer team competing under extremes of temperature in international climates would be best advised to concentrate on proper acclimatisation, nutrition and fluid replacement strategies prior to competition than on the specifics of clothing design.

In summary:-

1. Soccer-specific intermittent exercise induced an increase in foot skin temperature of a greater magnitude than during continuous exercise of the same average workload.
2. Soccer footwear does not have a significantly detrimental effect on physiological responses compared with training shoes.
3. The specification of phase control material examined in this thesis was not appropriate to enhance thermal comfort and therefore further development is necessary to address the problems of reduced heat loss and moisture build-up within goalkeepers' gloves.



4. Wearing a soccer training jacket may be detrimental for a soccer player in a cold and windy environment where heat preservation is required. The top may not be suitable in preventing overcooling, especially as the intermittent nature of soccer activity may result in periods of sweating followed by periods of chilling. The design of a suitable clothing ensemble is necessary to address this environmental challenge.
5. Environmental heat of 30°C may increase demands on heat loss mechanisms beyond an acceptable level while playing soccer resulting in fatigue and reduced exercise performance. Whereas a cool environment of 10°C appears to be optimal for soccer type activity.
6. Clothing composed of technical fabric gives no significant benefit over traditional fabric in compensating for the increased demands on heat loss mechanisms during soccer-specific intermittent exercise in a warm environment (30°C). No improvements in enhancing heat dissipation were observed.



## CHAPTER 9. REFERENCES



## 9. REFERENCES

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## CHAPTER 10. APPENDICIES



APPENDICES 1,5&7  
NOT SCANNED ON  
INSTRUCTION FROM  
UNIVERSITY



## **APPENDIX 1**

### **PUBLICATIONS OF WORK ARISING FROM THIS THESIS**



## **APPENDIX 2**

### **CALIBRATION PROCEDURES FOR GAS ANALYSIS SYSTEMS**



## **10.2 APPENDIX 2**

### **10.2.1 Sensormedics 2900 Metabolic Cart (Yorbalinda, California, USA)**

Calibration procedure:

1. Select system calibration <F2>
2. Choose <F1> flowmeter calibration
3. Attach valve to hose then attach piston to valve (the piston is the cylindrical tube located above the front wheels of the gas analyser)
4. Do 5 full stokes then press <SPACE> to display graph
5. Do 5 more flushes (only 4 will be displayed on the graph)
6. Repeat 5 more flushes
7. The % prediction on the right of the screen should be no more than 99%
8. If it is any less repeat the procedure by selecting “R”, to move to the next stage press <F10>
9. Select M.C. analyser cal. <F3>, <SPACE>
10. Press <SPACE> at “charge tank values”
11. Open cylinders using the spanner (about 4 turns) and ensure the system flow is at 250cc/min (located below keyboard) and wait for verification table
12. CLOSE TANKS
13. The machine is calibrated and ready for use



### 10.2.2 Pulmolab EX670 Mass Spectrometer (Morgan Medical, Gillingham, UK)

Calibration procedure (adapted from Bussell, 1999):

1. Click on the [Operate] button. In the Emission panel the heating dial will complete to 100%; there will be three visible traces (red, green and white); in the Control Panel the [Standby], [Exercise] and [Gas] buttons will be active. Five green lights should now be visible on the front of the Pulmolab machine (indicating the power, pump 1, pump 2, operate and sample are active).
2. Click on [Exercise] button to run the Pulmolab as a metabolic measuring system. The screen will change to one entitled EX670 System V2.21 showing four grey charts indicating gas traces.
3. Ensure that both ends of the blue capillary tube are inserted in to the front of the Pulmolab machine. The white end of the capillary tube is placed in the calibration gas output port {indicated by a blue triangle and circle with an arrow pointing to the right} and the blue end of the capillary tube inserted in the sample inlet tube connection port {indicated by a human symbol with an arrow pointing into a circle}.

#### 4. GAS CALIBRATION

- Connect the calibrator gas tube to the gas bottle
- Open the gas bottle and ensure that one bar of pressure is being released
- Press **F2 Cal-Gases** and a red message box appears stating Sensitivity Error which will shortly disappear and another message then appears stating Tuning in Progress followed shortly by Sampling Air - please wait. The graphs will be running red traces.
- Once the calibration is complete the graphs will return to running blue traces.
- Close the gas bottle and disconnect the calibration gas tube.
- The calibration can be quickly verified by gently breathing over the white tip of the blue capillary tube. The %O<sub>2</sub> and %CO<sub>2</sub> charts will fluctuate indicating the concentration of the expired gases (i.e. 16%O<sub>2</sub> and 3%CO<sub>2</sub>).
- The gas calibration is sufficient to for several hours' accurate measurement, but it is recommended before each subject.

#### 5. TURBINE CALIBRATION

- Assemble the mouth piece {pick up assembly, turbine cartridge, gas sampling port and saliva trap}
- Press **F3 Cal-Turb.** The screen will change and the message box at the bottom of the screen requests you "Make 10-Full



Strokes". Connect the 3-litre syringe pump to the mouthpiece using the grey rubber connector.

- Smoothly pump the syringe 10 times and the message box at the top of the screen counts through each pump. When 10 strokes have been completed the Mean Stroke Vol. will be displayed and you have the option to accept or reject the final volume.
- When the value is accepted the screen returns to the four gas traces.

## 6. TIME DELAY CALIBRATION

- This indicates the time between an instantaneous flow/volume event and the corresponding analysis event as measured by the system. The delay should be in the region of 100-200 ms due to the transit time of the gas into the system. Time delay changes with the length of the blue capillary tube.
- Press F4 Cal-Delay.
- Place the mouthpiece assembly into the mouth of the subject. Press [Enter] to begin the time delay sampling. Ask the individual to breath in - stop - breath out - stop to create a square wave effect.
- When sufficient breaths have been analysed a grey message box will appear stating the Delay Time and giving the option to accept or reject the value attained.
- When the value is accepted the screen returns to the 4 blue traces.

7. Now the system is calibrated and ready to run. By pressing **F7 - Run Test** the system will begin analysing the air being drawn into the Pulmolab system. Therefore, ensure the subject is ready to commence the testing session.



## **APPENDIX 3**

### **BLOOD ANALYSES**



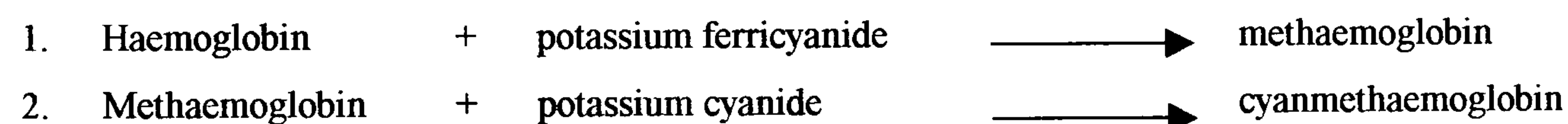
### 10.3 APPENDIX 3

#### 10.3.1 Laboratory Methods for Measurement of Haematocrit, Haemoglobin and Plasma Volume

##### 10.3.1.1 Haemoglobin

The concentration of haemoglobin in whole blood was determined using a Hemocue met-Hb Photometer system (Hemocue AB, Ängelholm, Sweden). The Hemocue system consists of a photometer and disposable microcuvettes containing dry reagents designed specifically for the measurement of haemoglobin. The microcuvettes act as a pipette, reaction vessel and measuring cuvette. Blood is drawn into the microcuvette, avoiding the introduction of air bubbles and then placed immediately onto the cuvette drawer and pushed into the Hemocue photometer for measurement.

The chemical reactions involved in this procedure are as follows:



Cyanmethaemoglobin is coloured and is quantified photometrically at a wavelength of 540 nm in the Hemocue photometer. When the end point of the reaction has been determined (approximately 30 - 60 s depending on concentration) the results are displayed in the LCD readout screen. The accuracy of the Hemocue system was determined before each measurement using the standard reference cuvette.

##### 10.3.1.2 Haematocrit

To determine haematocrit, venous blood was drawn into duplicate haematocrit tubes containing lithium heparin (anticoagulant), avoiding the introduction of air bubbles. The tubes were filled to approximately 75% and sealed at one end with Critoseal



(Gelman-Hawksley Ltd, Lancing, Sussex, UK). The haematocrit tubes were balanced on opposite sides of a micro-capillary centrifuge (Mikro 12-24 Zentrifugen, Hettich, Tuttlingen, Germany) and spun at 1,200g for 8 min. The tubes were then placed on a Hawksley Haematocrit reader (Gelman-Hawksley Ltd, Lancing, Sussex, UK) and the percentage of packed cell volume (PCV) was measured.

#### *10.3.1.3 Calculation of Plasma Volume Change (Dill and Costill, 1974)*

To determine changes in plasma volume during exercise haemoglobin is used as a marker as no significant changes in concentration occur over a short time period. Hence, a change in plasma volume will be reflected as a change in haemoglobin. Haematocrit is the measurement of packed cell volume as a percentage of the total blood volume. The combination of both these measurements allow the calculation of plasma volume change (Dill and Costill, 1974).

The following equations detail the method used to calculate plasma volume from measurements of haemoglobin concentration and haematocrit.

**Equation 10.1.** Calculation of blood volume after exercise.

$$BV_A = BV_B \times \left( \frac{Hb_B}{Hb_A} \right)$$

Where:

- $BV_A$  = Blood volume after exercise
- $BV_B$  = Blood volume before exercise (=100)
- $Hb_B$  = Haemoglobin concentration before exercise
- $Hb_A$  = Haemoglobin concentration after exercise



**Equation 10.2.** Calculation of red cell volume after exercise.

$$CV_A = BV_A \times Hct_A$$

Where:

$CV_A$  = Cell volume after exercise

$BV_A$  = Blood volume after exercise (from Equation 10.1)

$Hct_A$  = Haematocrit % after exercise

**Equation 10.3.** Calculation of plasma volume after exercise.

$$PV_A = BV_A - CV_A$$

Where:

$PV_A$  = Plasma volume after exercise

$BV_A$  = Blood volume after exercise (from Equation 10.1)

$CV_A$  = Cell volume after exercise (from Equation 10.2)

**Equation 10.4.** Calculation of percentage change in blood volume with exercise.

$$\Delta BV\% = 100 \left( \frac{BV_A}{BV_B} \right) / BV_B$$

Where:

$\Delta BV\%$  = Percentage change in blood volume following exercise

$BV_A$  = Blood volume after exercise (from Equation 10.1)

$BV_B$  = Blood volume before exercise (=100)

**Equation 10.5.** Calculation of percentage change in red cell volume with exercise.

$$\Delta CV\% = 100 \left( \frac{CV_A}{CV_B} \right) / CV_B$$



Where:

- $\Delta CV\%$  = Percentage change in red cell volume following exercise  
 $CV_A$  = Red cell volume after exercise (from Equation 10.2)  
 $CV_B$  = Red cell volume before exercise (= HctB)

**Equation 10.6.** Calculation of percentage change in plasma volume with exercise.

$$\Delta PV\% = 100 \left( \frac{PV_A}{PV_B} \right) / PV_B$$

Where:

- $\Delta PV\%$  = Percentage change in plasma volume following exercise  
 $PVA$  = Plasma volume after exercise (from Equation 10.3)  
 $PVB$  = Plasma volume before exercise (100-HctB)

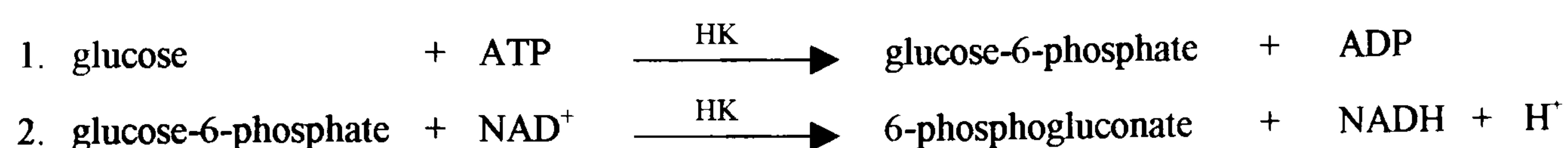
### 10.3.2 Laboratory Methods for Measurement of Metabolites and Hormones

All analyses were performed in duplicate to give a mean value for each sample.

#### 10.3.2.1 Plasma Glucose

The concentration of plasma glucose was determined using a commercially available kit (IL Test™ Glucose, Instrumentation Laboratory, Lexington, USA), which utilised enzymatic methods for bio-chromatic analysis in an IL Monarch centrifugal analyser (Instrumentation Laboratory, Lexington, USA).

The enzymatic reactions involved in this procedure involve a coupled hexokinase procedure:



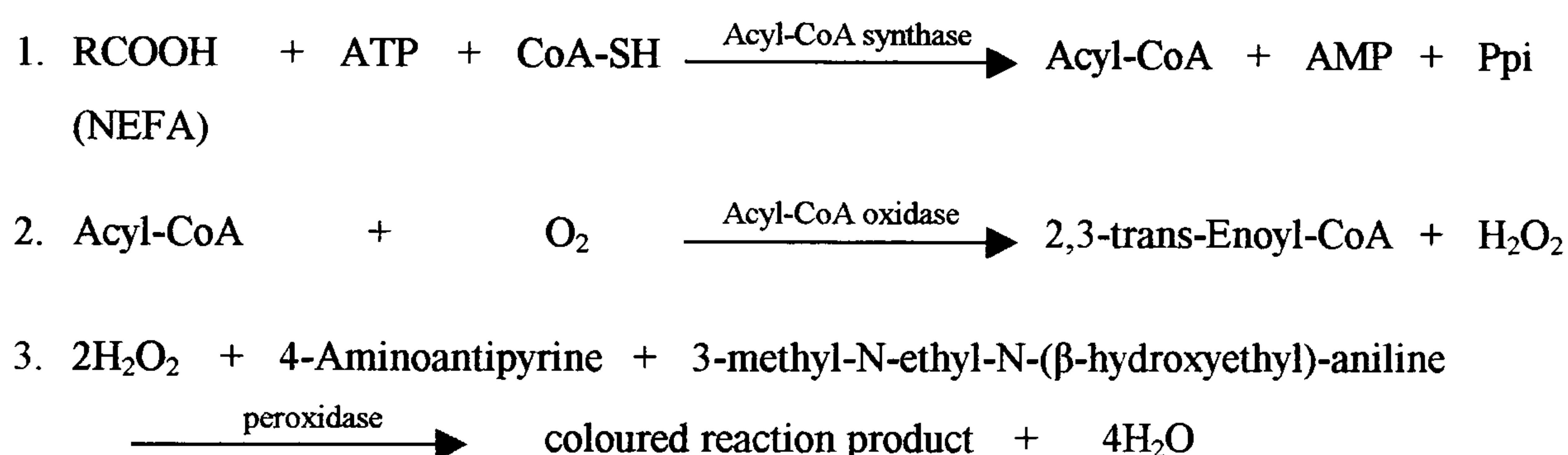


The absorbance due to conversion from  $\text{NAD}^+$  to NADH is directly proportional to the glucose present in the sample. The concentration of NADH is measured photometrically at a wavelength 340 nm.

#### 10.3.2.2 *Non Esterified Fatty Acids in Plasma*

The concentration of plasma NEFA was determined using a commercially available kit (WAKO NEFA C kit, Alpha Laboratories Ltd., Eastleigh, UK), which utilised enzymatic methods for bio-chromatic analysis in an IL Monarch centrifugal analyser (Instrumentation Laboratory, Lexington, USA).

The enzymatic reactions involved in this procedure:



The absorbance due to conversion from  $\text{NAD}^+$  to NADH is directly proportional to the glucose present in the sample. The concentration of NADH is measured photometrically at a wavelength 340 nm.

#### 10.3.3 Measurement of Plasma Osmolality

The Advanced<sup>™</sup> Osmometer (Advanced Instruments Inc., Norwood, Massachusetts, USA) was used for the precise determination of the concentration of solutions by means of freezing point measurement.



Osmolality is the unit of measurement and is the osmoles of solute particles per kilogram of pure solvent. The unit takes into account the effect of dissociation.

When a solute is dissolved in a solvent the physical properties of the solvent are altered, In particular, the freezing point is depressed, the boiling point is raised, the osmotic pressure is increased and the vapour pressure is lowered. Measurement of the freezing point of a sample allows for the calculation of concentration. When a solution is super cooled several degrees below the freezing point and the sample is frozen, heat of fusion is released causing temperature to rise to a plateau where liquid / solid equilibrium occurs, this is the freezing point and can be used to determine the concentration of the solvent.

#### *10.3.3.1 Procedure for Analysis Using the Advanced™ Osmometer*

1. The sample is introduced into the cooling chamber using the 20 µl Advanced™ pipette. The sample is automatically rapidly cooled and the display reads "Cooling Sample".
2. When the temperature of the sample reaches 0°C the display begins counting upwards and the cooling rate slows.
3. When the sample has been sufficiently super cooled, a mechanical pulse induces the sample to freeze.
4. As the sample freezes the heat of fusion warms the sample towards the freezing point and the display counts quickly downwards and eventually reaches equilibrium.
5. When the display reading becomes constant the equilibrium has been reached at freezing point. The display locks in the resultant osmolality, reading, for example, "Osmolality 300 mOsm".
6. The sample may be removed from the chamber and the machine is now ready for the next sample.



## **APPENDIX 4**

### **TREADMILL INFORMATION**



## 10.4 APPENDIX 4

### 10.4.1 Speed Listing for New Outfielder Soccer-Specific Treadmill Protocol.

Time Period	Action	Time
00:25	Walking - 06kph	00:00
00:49	Jogging - 12 kph	00:25
00:12	Cruising - 15kph	01:14
00:26	Jogging - 12 kph	01:26
00:08	Sprinting - 21kph	01:52
00:25	Walking - 06kph	02:00
00:26	Jogging - 12 kph	02:25
00:12	Cruising - 15kph	02:51
00:25	Walking - 06kph	03:03
00:12	Cruising - 15kph	03:28
00:25	Walking - 06kph	03:40
00:49	Jogging - 12 kph	04:05
00:12	Cruising - 15kph	04:54
00:33	Walking - 06kph	05:06
00:49	Jogging - 12 kph	05:39
00:12	Cruising - 15kph	06:28
00:26	Jogging - 12 kph	06:40
00:09	Sprinting - 21kph	07:06
00:25	Walking - 06kph	07:15
00:26	Jogging - 12 kph	07:40
00:12	Cruising - 15kph	08:06
00:15	Stand	08:18
00:25	Walking - 06kph	08:33
00:12	Cruising - 15kph	08:58
00:25	Walking - 06kph	09:10
00:12	Cruising - 15kph	09:35
00:08	Sprinting - 21kph	09:47
00:25	Walking - 06kph	09:55
00:49	Jogging - 12 kph	10:20
00:25	Walking - 06kph	11:09
01:00	Stand	11:34
00:26	Jogging - 12 kph	12:34
00:08	Sprinting - 21kph	13:00
00:25	Walking - 06kph	13:08
00:26	Jogging - 12 kph	13:33
00:25	Walking - 06kph	13:59
00:12	Cruising - 15kph	14:24
00:25	Walking - 06kph	14:36
00:26	Jogging - 12 kph	15:01
00:25	Walking - 06kph	15:27
00:08	Sprinting - 21kph	15:52
00:25	Walking - 06kph	16:00
00:26	Jogging - 12 kph	16:25
00:12	Cruising - 15kph	16:51
00:30	Stand	17:03
00:25	Walking - 06kph	17:33
00:12	Cruising - 15kph	17:58
00:08	Sprinting - 21kph	18:10
00:25	Walking - 06kph	18:18
00:49	Jogging - 12 kph	18:43
00:25	Walking - 06kph	19:32
00:08	Sprinting - 21kph	19:57
00:30	Walking - 06kph	20:05
00:26	Jogging - 12 kph	20:35
00:08	Sprinting - 21kph	21:01
00:25	Walking - 06kph	21:09
00:26	Jogging - 12 kph	21:34
01:00	Stand	22:00

Time Period	Action	Time
00:25	Walking - 06kph	23:00
00:49	Jogging - 12 kph	23:25
00:12	Cruising - 15kph	24:14
00:26	Jogging - 12 kph	24:26
00:08	Sprinting - 21kph	24:52
00:25	Walking - 06kph	25:00
00:26	Jogging - 12 kph	25:25
00:12	Cruising - 15kph	25:51
00:25	Walking - 06kph	26:03
00:12	Cruising - 15kph	26:28
00:25	Walking - 06kph	26:40
00:49	Jogging - 12 kph	27:05
00:12	Cruising - 15kph	27:54
00:33	Walking - 06kph	28:06
00:49	Jogging - 12 kph	28:39
00:12	Cruising - 15kph	29:28
00:26	Jogging - 12 kph	29:40
00:09	Sprinting - 21kph	30:06
00:25	Walking - 06kph	30:15
00:26	Jogging - 12 kph	30:40
00:12	Cruising - 15kph	31:06
00:15	Stand	31:18
00:25	Walking - 06kph	31:33
00:12	Cruising - 15kph	31:58
00:25	Walking - 06kph	32:10
00:12	Cruising - 15kph	32:35
00:08	Sprinting - 21kph	32:47
00:25	Walking - 06kph	32:55
00:49	Jogging - 12 kph	33:20
00:25	Walking - 06kph	34:09
01:00	Stand	34:34
00:26	Jogging - 12 kph	35:34
00:08	Sprinting - 21kph	36:00
00:25	Walking - 06kph	36:08
00:26	Jogging - 12 kph	36:33
00:25	Walking - 06kph	36:59
00:12	Cruising - 15kph	37:24
00:25	Walking - 06kph	37:36
00:26	Jogging - 12 kph	38:01
00:25	Walking - 06kph	38:27
00:08	Sprinting - 21kph	38:52
00:25	Walking - 06kph	39:00
00:26	Jogging - 12 kph	39:25
00:12	Cruising - 15kph	39:51
00:30	Stand	40:03
00:25	Walking - 06kph	40:33
00:12	Cruising - 15kph	40:58
00:08	Sprinting - 21kph	41:10
00:25	Walking - 06kph	41:18
00:49	Jogging - 12 kph	41:43
00:25	Walking - 06kph	42:32
00:08	Sprinting - 21kph	42:57
00:30	Walking - 06kph	43:05
00:26	Jogging - 12 kph	43:35
00:08	Sprinting - 21kph	44:01
00:25	Walking - 06kph	44:09
00:26	Jogging - 12 kph	44:34
	STOP	45:00



### 10.4.2 Programme Input Steps for HP Cosmos Pulsar Treadmill

Programme steps for input into Pulsar treadmill (HP Cosmos, Nussforf-Traunstein, Germany) with correct key presses and including input of treadmill acceleration settings.

PROCEDURE	PROG. STEP	INPUT	DESCRIPTION
1	-	STORE 90	Enter the program number for memory location to be programmed. If the location is free, "S01" will appear in the distance display. If the location is already used, the command "STORE 90" will need to be entered 4 times (overwrite protection) in order to edit or delete the memory location
2	1	OPTION 4	If the "OPTION" key is pressed, a digit indicating the acceleration will blink at the left side of the distance display. If "4" is entered, acceleration step 4 is selected. Following that the speed may be entered
3	1	060	Enter the speed, 6.0 km h <sup>-1</sup>
4	1	0025	Enter the time, 00:25 min
5	1	00	Enter the inclination of 0%
-	-	-	"S02" for step 2 appears
6	2	OPTION 4	Enter the acceleration, 4
7	2	120	Enter the speed, 12.0 km h <sup>-1</sup>
8	2	0049	Enter the time, 00:49 min
9	2	00	Enter the inclination of 0%
-	-	-	"S03" for step 3 appears
10	3	OPTION 4	Enter the acceleration, 4
11	3	150	Enter the speed, 15.0 km h <sup>-1</sup>
12	3	0012	Enter the time, 00:12 min
13	3	00	Enter the inclination of 0%
-	-	-	"S04" for step 4 appears
14	4	OPTION 4	Enter the acceleration, 4
15	4	120	Enter the speed, x km h <sup>-1</sup>
16	4	0026	Enter the time, 00:26 min
17	4	00	Enter the inclination of 0%
-	-	-	"S05" for step 5 appears
18	5	OPTION 4	Enter the acceleration, 4
19	5	210	Enter the speed, 21.0 km h <sup>-1</sup>
20	5	0008	Enter the time, 00:08 min
21	5	00	Enter the inclination of 0%
-	-	-	"S06" for step 6 appears
22	6	OPTION 4	Enter the acceleration, 4
23	6	060	Enter the speed, 6.0 km h <sup>-1</sup>
24	6	0025	Enter the time, 00:25 min
25	6	00	Enter the inclination of 0%
-	-	-	"S07" for step 7 appears
26	7	OPTION 4	Enter the acceleration, 4
27	7	120	Enter the speed, 12.0 km h <sup>-1</sup>
28	7	0026	Enter the time, 00:26 min
29	7	00	Enter the inclination of 0%
-	-	-	"S08" for step 8 appears



30	8	OPTION 4	Enter the acceleration, 4
31	8	150	Enter the speed, 15.0 km h <sup>-1</sup>
32	8	0012	Enter the time, 00:12 min
33	8	00	Enter the inclination of 0%
-	-	-	"S09" for step 9 appears
34	9	OPTION 4	Enter the acceleration, 4
35	9	060	Enter the speed, 6.0 km h <sup>-1</sup>
36	9	0025	Enter the time, 00:25 min
37	9	00	Enter the inclination of 0%
-	-	-	"S10" for step 10 appears
38	10	OPTION 4	Enter the acceleration, 4
39	10	150	Enter the speed, 15.0 km h <sup>-1</sup>
40	10	0012	Enter the time, 00:12 min
41	10	00	Enter the inclination of 0%
-	-	-	"S11" for step 11 appears
ETC.....			
x	x	SET	Press "SET" to end and save the programme
x	-		"S01" appears in the distance display. Press "+" or "-" to go up and down through the programme steps. If a setting is altered the correction must be saved by pressing "SET".
		STOP	Ends the programming procedure, the programme number "90" will then appear in the speed display.

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## **APPENDIX 5**

### **STATISTICAL PROCEDURES**



## **APPENDIX 6**

### **FORMS AND QUESTIONNAIRES**



## 10.6 APPENDIX 6

### 10.6.1 JMU Standard Consent Form (EC3)

<b>LIVERPOOL JOHN MOORES UNIVERSITY</b>	
<b>FORM OF CONSENT TO TAKE PART AS A SUBJECT IN A RESEARCH PROJECT</b>	
<b>Title of project/procedure:</b>	
<p>I, ..... agree to take part in  <b>(Subject's full name)*</b></p> <p>the above named project/procedure, the details of which have been fully explained to me and described in writing.</p>	
Signed ..... (Subject)	Date .....
<p>I, ..... certify that the details of this  <b>(Investigator's full name)*</b></p> <p>project/procedure have been fully explained and described in writing to the subject named above and have been understood by him/her.</p>	
Signed ..... (Investigator)	Date .....
<p>I, ..... certify that the details of this  <b>(Witness' full name)</b></p> <p>project/procedure have been fully explained and described in writing to the subject named above and have been understood by him/her.</p>	
Signed ..... (Witness)	Date .....
<b>NB</b> The witness must be an independent third party.	
* Please print in block capitals	



## 10.6.2 Subject Suitability Questionnaire

### SUBJECT QUESTIONNAIRE

Please complete this questionnaire as fully as possible.

\* Delete as necessary

#### PERSONAL DETAILS

Full Name :

Address :

Postcode :

Telephone Number :

E-mail:

D.O.B. :

Boot Size:

#### FITNESS LEVEL - SOCCER

Soccer Level :

Amateur / Semi-Professional \*

Average training sessions per week?

1 / 2 / 3 / 4 / 5+ \*

Average training session duration?

Up to 1 hr / 1-2 hrs / 2-3 hrs / 3 hrs+ \*

Average matches per week in season?

1 / 2 / 3+ \*

Regular training (min. weekly) in other sport(s)?

Yes / No \*

If YES, what sport(s)?

#### INJURY

Have you been injured in the past 6 months? Yes / No \*

If YES, describe your injury:

Has this prevented you from training? Yes / No \*

If YES, for what period of time?



**HEALTH**

Do you have any health problems	Yes / No	If YES, please give details.
(i.e. diabetes, epilepsy, allergies)?	*	

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Are you taking any medication?	Yes / No	*
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Have you ever had heat stroke?	Yes / No	*
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Do you smoke?	Yes / No	*	If YES, how many per day?
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Do you drink alcohol?	Yes / No	*	If YES, how many units per week?
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Any further necessary information:

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### 10.6.3 Typical Subject Information Sheet

**Project Title:** Intermittent Soccer-Specific Exercise in Cold, Normal and Hot Environments.

**Project Supervisor:** Dr Tim Cable

**Researcher and Laboratory Supervisor:** Alison Purvis

**Assistants:** David Low and David Jackson

**Purpose of Study:** The aim of the study is to investigate the effects of different environments on metabolic, physiological and thermoregulatory responses during soccer-specific intermittent exercise.

**Procedures:** You will be required to attend a total of 4 laboratory-based sessions run over a maximum of 4 weeks. It will be necessary for you to initially complete a  $\text{VO}_2$  max test followed by three further experimental trials all of which are conducted on a motorised treadmill. The  $\text{VO}_2$  max assessment will take approximately 1 hour and each experimental trial will take approximately 2 hours. This time includes pre-exercise measurements and preparation, the exercise period and post-exercise measurements.

The  $\dot{\text{V}}\text{O}_{2\text{ max}}$  test requires you to run to exhaustion while continuous measurements of oxygen consumption and heart rate are taken.

The three experimental test sessions will each involve you participating in a 45 minute soccer-specific treadmill run conducted in three different temperature environments: Cold ( $10^\circ\text{C}$ ), normal ( $20^\circ\text{C}$ ) and hot ( $30^\circ\text{C}$ ).

Prior to starting the exercise period and post exercise, resting measurements of heart rate, skin blood flow, core temperature and skin temperature will be taken while lying supine. These measurements will also be taken continuously during the exercise period. Heart rate is measured using a chest strap and recording watch, core temperature is measured using a self-inserted rectal probe, skin temperature is calculated using the measurements of skin thermistors in four locations: chest, arm, thigh and shin and skin blood flow is measured using a sensor placed upon the skin. Nude body mass will also be measured before and after exercise, this will be conducted by the subject himself in a private room.

During the test sessions you will be expected to undertake four blood samples:

1. A venous blood sample shortly before each test.
2. A finger-prick blood sample mid-way through the exercise test.
3. A finger-prick blood sample immediately after the exercise test.
4. A venous blood sample 5 minutes after each test.

The blood samples will be analysed for haemoglobin, plasma volume, lactate, free fatty acids, prolactin, glucose, glycerol, cortisol, growth hormone, adrenaline and noradrenaline.

Oxygen consumption will be measured continuously during the exercise period through a mouthpiece.

At five-min intervals you will be asked to give a rating of your perceived exertion (i.e. how difficult or strenuous you feel the exercise is) and rating of thermal stress from lists provided.



You are asked to abstain from alcohol and strenuous exercise for 24 hours prior to testing, caffeine for at least 12 hours prior and food for 3 hours prior. You are reminded to hydrate properly in the 24 hours preceding the experiment day as you will be unable to drink during testing. The recommended minimum fluid intake is 1.5 litres and this should not include drinks containing caffeine (causes dehydration).

**Informed consent will be obtained using a JMU standard consent form, which you will be asked to sign before starting this study. If you are unsure about any of the procedures used in this study feel free to ask. You must freely volunteer to be a subject and are able to withdraw, without prejudice, at any time.**



## **APPENDIX 7**

### **MANUFACTURERS CLOTHING INFORMATION**