CLOTHING AND THERMOREGULATION DURING SUB MAXIMAL CYCLING: EFFECTS OF HEAT, HUMIDITY AND FABRIC

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ABSTRACT

The investigation evaluated if wearing a specialised under garment, termed base layer, could significantly alter physiological or thermoregulatory responses to sub maximal cycling. Twelve males completed a 60 minute continuous cycling protocol (60% $\dot{V}O_{2max}$) twice within three environmental conditions (ambient (20 °C, 35% relative humidity) (RH)), hot/dry (30 °C, 35% RH) and hot/humid (30 °C, 80% RH)). Protocols were completed in a repeated measures counterbalanced design within a controlled environmental chamber at the same time of day. Participants wore the same cotton shorts, socks and running trainers alongside either a 100% cotton or a base layer t-shirt for each trial. Values for core temperature (T_c), mean skin temperature (T_{sk}), heat rate (HR), oxygen uptake ($\dot{V}O_2$), rate of perceived exertion (RPE), thermal comfort and sweating sensation were recorded at 15, 30, 45 and 60 minutes whilst sweat loss (S_{Loss}) was calculated post exercise. All variables were calculated into delta values (Δ) (cotton – base layer) and analysed using a two-way analysis of variance (ANOVA) excluding Δ S_{Loss} which was analysed using a One-way ANOVA. Where necessary Bonferroni correct T-tests were implemented to further investigate any significant effects. Results showed base layers significantly reduced $\dot{V}O_2$ ($P = 0.038$) whilst increasing S_{Loss} ($P < 0.001$) within the hot/dry condition. Further Bonferroni corrected T-test revealed base layers reduced $\dot{V}O_2$ between 15 and 45 ($P = 0.048$), 15 and 60 ($P = 0.017$), and 45 and 60 minutes ($P = 0.049$) within the hot/dry condition. No significant differences were detected in any other variables. The investigation reports that a specialised base layer may provide both a thermoregulatory and physiological advantage during sub maximal cycling within hot/dry environmental conditions.

Authors Declaration:

I declare that the work in this thesis was carried out in accordance with the regulations of the University of Gloucestershire and is original except where indicated by specific reference in the text. No part of the thesis has been submitted as part of any other academic award. The thesis has not been presented to any other education institution in the United Kingdom or overseas. Any views expressed in the thesis are those of the author and in no way represent those of the University.

Signed ......[redacted]...................... Date ......11·7·2011..............

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CHAPTER I

INTRODUCTION

Optimal functioning of the human body is dependant upon maintaining an optimal thermal state (37.5 ± 1 °C) (Moran and Mendal, 2002). Heat is produced primarily by metabolism and lost through exchange with the environment and the evaporation of bodily fluids (Hensem, 1990). Human metabolism is inefficient whereby ~70% of chemical energy is converted to thermal energy during sub maximal exercise (Whipp and Wasserman, 1969; Taylor, 2006). Therefore, when metabolic heat production combines with external heat from the environment a physiological and thermoregulatory challenge is created (Hargreaves, 2008). Athletes must then achieve a balance between avoiding hyperthermia and maintaining adequate performance intensity without compromising personal safety (Reilly *et al.,* 2006). Consequently, sub maximal performance declines within hot environmental conditions (Hargreaves and Fabbraio, 1998; Kay *et al.,* 2001; Nybo *et al.,* 2001; Watson *et al.,* 2004; Tucker *et al.,* 2006) as thermoregulation, specifically core temperature (T_c), becomes a key determinant of performance (Cheung *et al.,* 1998; Parkin *et al.,* 1999; Nybo and Nielsen, 2001; Hasegawa *et al.,* 2005). This is apparent from the poor endurance performance times at major championships when environmental temperature and/or relative humidity (RH) is high (Terrados and Maughan, 1995). Subsequently, performance in hot environments (>29 °C) becomes increasingly influenced by tactical decisions (re-hydration, feeding and pacing strategies) in addition to physiological attributes (Terrados and Maughan, 1995).

Environmental temperature (>29 °C) limits performance through reductions in thermoregulatory efficiency and variations in blood flow, muscle metabolism (Gonzalez-Alonso *et al.,* 1998) and the central nervous system (CNS). Within such conditions thermoregulation relies primarily on evaporative heat loss (Gavin *et al.,* 2001; Taylor, 2006; Wendt *et al.,* 2007) whereby any improvement to the evaporation of sweat may provide a thermoregulatory and physiological advantage (Gavin *et al.,* 2001).

Numerous strategies to achieve improvements in evaporative heat loss have been identified. The most common of which include pre performance cooling (Cotter *et al.,* 2001; Hasegawa *et al.,* 2005; Castle *et al.,* 2006) and heat acclimation (Buono *et al.,* 1998; Moreira *et al.,* 2005; Patterson *et al.,* 2004) which both have been shown to improve thermoregulation and provide a physiological advantage (Buono *et al.,* 1998; Kay *et al.,* 1999; Hasegawa *et al.,* 2005; Hunter *et al.,* 2006). However, heat acclimation is time consuming and expensive, whilst pre performance cooling is equally restricted by equipment and competition restraints (Kay and Marino, 2000). Alternatively, the type of clothing worn during performance may offer a practical strategy for improving both thermoregulation and physiological responses to exercise in the heat.

Clothing forms a microenvironment above the skin which represents a layer of insulation that decreases the potential for evaporative heat loss (Cheung *et al.,* 2000). Clothing was originally identified to increase both skin temperature (T_{sk}) and T_c through reductions in thermoregulatory efficiency (Roberts *et al.,* 2007; Wendt *et al*., 2007). However, advances in textile research identified that thermoregulation could be improved, when compared to traditional fabrics, by manipulating the physical properties of a garment (Roberts *et al.,* 2007). Garments with larger interstices (the gap between two adjacent fibres) potentially reduce T_{sk} through increased air circulation (Houdas and Ring, 1982) whilst smaller fibre diameters optimise evaporative heat loss through improvements to moisture transfer and retention (Nielson, 1986; Havenith, 2002). These advances prompted specialised under garments, termed base layers, to be introduced into the athletic clothing market.

Base layers are predominately constructed from Lycra and Meryl Microfibre™ (Skins, 2009) and worn next to the skin beneath official team kit. Manufacturers claim they improve both physiological and thermoregulatory responses to exercise through enhanced wicking and regain properties that optimise evaporative cooling (Skins, 2009a). Base layers have been predominantly evaluated in relation to power sports (Kraemer *et al.,* 1996; Doan *et al.,* 2003) and recovery (Berry *et al.,* 1990; Duffield and Portus, 2007) whereby significant improvements in both areas are noted (Kraemer *et al.,* 1996; Doan *et al.,* 2003; Duffield and Portus, 2007). However, despite their use within sub maximal performance becoming widespread (Houghton *et al.,* 2009) inadequate independent research becomes apparent. To date only two studies (Gavin *et al.,* 2001; Roberts *et al.,* 2007) have evaluated base layers during sub maximal performance with both failing to support any claims that an advantage manifests when wearing a base layer.

Roberts *et al.,* (2007) reported no significant difference in T_c (base layer vs. cotton) which is consistent within Gavin *et al.,* (2001) who also reported no significant difference in oxygen consumption ($\dot{V}O_2$), heart rate (HR), T_c or T_{sk}. However, the short exercise duration (30-min) within Gavin *et al.,* (2001) and cool environmental conditions (20 °C; 47% RH) within Roberts *et al.,* (2007) induced inadequate thermal stress as maximum mean T_c remained within optimal limits. Subsequently, both investigations failed to significantly affect physiological responses to exercise (Gonzalez-Alonso *et al.,* 1999; Kay *et al.,* 2001) whilst minimising any potential physiological advantages provided by the base layer. Consequently, both studies failed to adequately investigate base layers in relation to the true physiological and thermoregulatory demands of sub maximal exercise within hot environments. These numerous methodological issues make a true comparison of the findings impossible whilst they also limit any practical application and acceptance of any research conclusions, as detailed in section 2.5.3: Critique of Base Layer Research. Therefore, protocols that induce superior thermal stress may offer more practical knowledge on base layers which are designed to provide physiological and thermoregulatory advantages during performance within hot environments.

Increases in thermal stress can be achieved in several forms, primarily through increases in exercise intensity and/or duration. However, as intensity increases time to fatigue decreases (Poole & Richardson, 1997), thus any increase in intensity must not limit exercise duration to an extent that the thermoregulatory system is not stressed prior to fatigue. Secondly, increases in RH will induce superior thermal stress as the rate of evaporative heat loss required to maintain an optimal thermal state potentially exceeds the evaporative capacity of the environment (Adams *et al.,* 1992; Candas & Hoeft, 1995; Cheung, 2000). This understanding alongside the lack of independent research suggests a need to evaluate base layers within varied environmental conditions where exercise duration and intensity induce adequate thermal stress prior to fatigue. Subsequently, to date both thermoregulatory and physiological responses whilst wearing base layers during sub maximal exercise has yet to be evaluated within varied environmental conditions where exercise duration exceeds 45 minutes.

The present investigation aimed to evaluate if, when compared to cotton, a base layer could significantly alter either physiological or thermoregulatory responses to sub maximal exercise. The investigation evaluated the base layer within three different environmental conditions (ambient, hot-dry and hot-humid) and aimed to determine if any physiological or thermoregulatory advantages are evident whilst identifying in which environmental conditions these manifest.

CHAPTER II

REVIEW OF LITERATURE

2.1: Thermoregulation

An optimal thermal state (37.5 ± 1°C) is maintained through four mechanisms of heat loss: convection, conduction, radiation and evaporation (Cheuvront and Haymes, 2001; Wendt *et al.*, 2007). Thermoregulation relies upon acute physiological responses that depend upon sensory information from both central and peripheral thermo-receptors located in the hypothalamus and skin respectively (Astrand *et al.*, 2003). Thermo-receptors detect variations in T_c and relay sensory information to the hypothalamus where the stimulation of neural autonomic outflow causes a cascade of involuntary vasomotor and cardiovascular responses relating to thermoregulation, which is calculated by the heat balance equation (1):

$$\mathbf{S = M - W \pm R \pm C \pm K - E} \quad \text{...}(1)$$

Where: S = Heat storage ($W{\cdot}m^{-2}$); M = Metabolic heat production; W = Heat used to perform external work; R = Radiative heat exchange; C = Convective heat exchange; K = Conductive heat exchange; E = Evaporative heat loss.

(Cheuvront and Haymes, 2001)

The heat balance equation highlights the problems faced by the thermoregulatory system during exercise in hot environments. The plateau of peripheral blood flow seen during exercise in hot environments limits the ability to lose heat via non-evaporative mechanisms (Wendt *et al.*, 2007) whilst these mechanisms are potentially reversed when metabolic heat production and/or environmental heat reverses the thermal gradient between the T_{sk} and the air (Taylor, 2006; Wendt *et al.*, 2007). Consequently, during exercise within hot environments thermoregulation relies primarily upon evaporative heat loss which is dictated by both the thermoregulatory efficiency of the athlete and the evaporative capacity of the environment (Taylor, 2006). However, the ability for the environment to assist evaporative heat loss decreases as either environmental temperature or RH increase. Consequently, to avoid hyperthermia during exercise in the heat sweat rate increases whilst the vasodilatation of capillaries increases skin perfusion at the expense of muscle blood flow (Terrados and Maughan, 1995). These thermoregulatory processes induce various physiological responses relating to metabolism, CNS function and hormone release, all of which contribute to the early onset of hyperthermia-induced fatigue (Gonzalez-Alonso *et al.,* 1999; Nybo, 2008).

2.2: Hyperthermia-induced Fatigue: Central or Peripheral?

2.2.1: Hyperthermia-induced Fatigue

Once an optimal thermal state is lost sub maximal performance (<80% maximal oxygen consumption ($\dot{V}O_{2max}$)) declines via the early onset of fatigue (Gonzalez-Alonso *et al.,* 1999; Kay *et al.,* 2001; Nybo *et al.,* 2002; Tucker *et al.,* 2004; Watson *et al.,* 2005; Tucker *et al.,* 2006). Variations in metabolism, circulation and the CNS have been identified within the fatigue process (Nybo and Secher, 2004; Nybo, 2007) whilst a conflict between its origin (peripheral vs. central) is evident. Several researchers propose that substrate availability, lactate accumulation and variations in blood flow induce peripheral fatigue (Hargreaves & Fabbraio, 1998; Gonzalez-Alonso & Calbet, 2003) whilst others argue peripheral mechanisms fail to explain the reduction in performance; thus hypothesising CNS variations provoke central fatigue (Nybo & Neilsen, 2001; Nybo & Secher, 2004).

2.2.2: Cardiovascular Function and Peripheral Fatigue

The cardiovascular system is essential to thermoregulation (Armstrong, 2000) as adequate heat loss requires skin perfusion to increase via the vasodilatation of capillaries (Kenny & Johnson, 1992; Wendt *et al.*, 2007). During low intensity exercise (<60% $\dot{V}O_{2max}$) in hot environmental conditions both muscle blood flow and thermoregulatory efficiency are maintained as blood flow to internal organs declines to meet peripheral demands (Nielsen *et al.,* 1990). However, during higher intensity exercise (>60% $\dot{V}O_{2max}$) the ability to maintain adequate muscle and peripheral blood flow declines as peripheral demands increase by ~ 6-8 $L \cdot min^{-1}$ (Charkoudian, 2003) whilst cardiac output, stroke volume and arterial blood pressure decline (Rowell *et al.,* 1966; Gonzalez-Alonso, 2007). Consequently, during prolonged high intensity exercise in the heat cardiovascular and thermoregulatory function are compromised as the maintenance of adequate peripheral blood flow to avoid hyperthermia relies on elevations in HR to compensate for the decline in cardiac output (Gonzalez-Alonso, 2007). However, elevations in HR fail to maintain cardiac output (Gonzalez-Alonso & Calbet 2003) which causes peripheral blood flow to increase at the expense of skeletal muscle (Gonzalez-Alonso, 2007). This blood flow variation, termed peripheral steal, alongside elevations in T_c increases both lactate production and the release of the norepinephrine and epinephrine hormones (Gonzalez-Alonso *et al.,* 1998). Consequently, metabolites accumulate within skeletal muscle whilst the utilisation of glucose increases at the expense of fat metabolism as glucose supply to skeletal muscle and the catabolism of glycogen to glucose in the liver increases (Febbraio *et al.,* 1994; Gonzalez-Alonso *et al.,* 1999). However, some authors argue that muscle glycogen stores are not depleted upon exhaustion (Galloway, 1999; Nybo and Secher, 2004) and this fails to sufficiently explain hyperthermia-induced peripheral fatigue (Gonzalez-Alonso *et al.,* 1998) as reductions in muscle blood flow fail to inhibit glucose delivery to, and lactate removal from, skeletal muscle (Gonzalez-Alonso *et al.,* 1999). Therefore, despite the obvious decline in muscle blood flow the peripheral steal and elevations in T_c create problems for both performance and thermoregulation through variations in muscle metabolism, hormone release and lactate production (Gonzalez-Alonso, 2007).

Research shows the limiting factors of sub maximal exercise in hot environments are primarily associated with the ability to maintain cardiac output and meet both muscle and peripheral blood flow demands (Gonzalez-Alonso *et al.,* 1999). Other factors such as variations in muscle metabolism, the accumulation of metabolites and both hormone and lactate production seem to be of minor importance (Nybo, 2008). Figure 2.1 outlines these key processes of hyperthermia-induce peripheral fatigue.

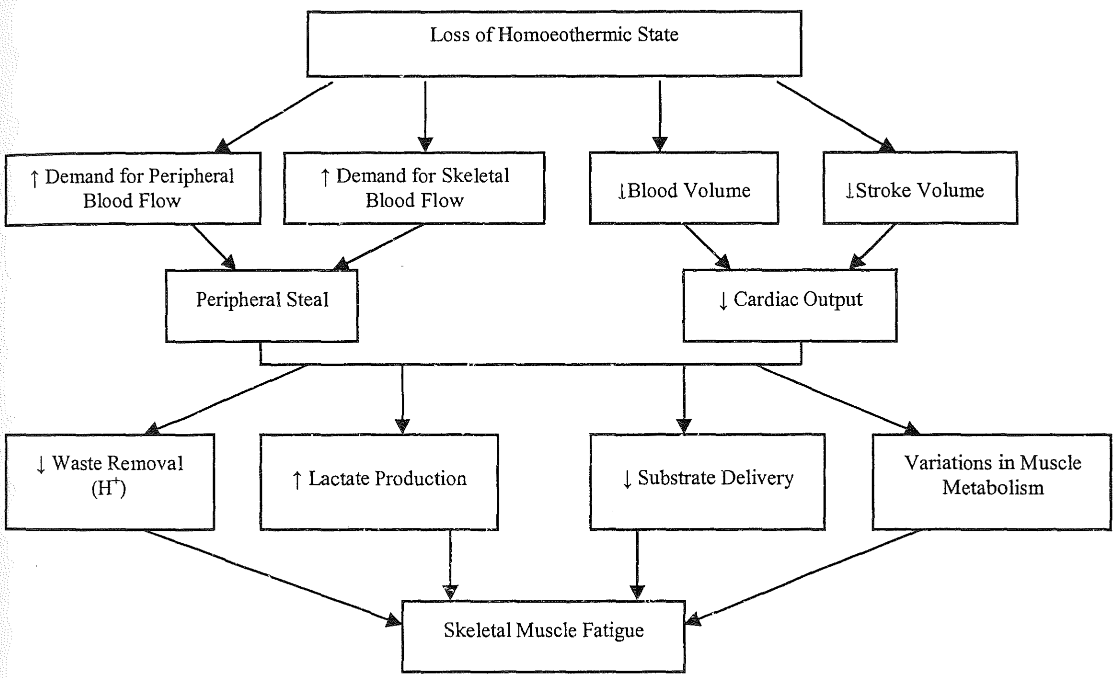

Figure 2.1: Schematic model of hyperthermia induced peripheral fatigue (Adapted from Abiss and Laursen, 2005).

2.2.3: CNS Decline and Central Fatigue

In contrast to the above, several authors agree the limiting factor of sub maximal exercise in hot environments relates to CNS decline and central fatigue (Nielsen *et al.,* 1993; Gonzalez-Alonso *et al.*, 1999; Hasegawa *et al.,* 2005). Central fatigue emerges as a progressive increase in the RPE alongside a continuing slowing of the electroencephalogram as T_c elevates beyond 38 °C (Nybo and Nielsen, 2001).

During sub maximal exercise in hot environments central motor activation declines as elevations in cerebral temperature increase the inhibitory signals from thermo-receptors (Nybo, 2008). Supportive evidence shows that motor activation is inhibited by elevated temperatures in the CNS as exercise intensity decreased when hypothalamic temperature was independently increased (Caputa *et al.,* 1986; Nybo and Nielsen, 2001). Elevations in cerebral temperature increase the firing frequency necessary to sustain adequate motor activation (Nybo, 2008) whereby the central activation of skeletal muscle becomes low during repeated muscle contractions (Nybo, 2008). Additionally, variations in the release of certain neurotransmitters associated with elevations in cerebral temperature further decreased the central activation of skeletal muscle during prolonged exercise (Nybo and Secher, 2004; Secher *et al.,* 2008). This association between central fatigue and a decline in central motor activation (Kent-Braun, 1999; Nybo and Nielsen, 2001; Todd *et al.*, 2005) and/or the ability of the CNS to supply constant drive is supported by various authors (Armstrong and Maresh, 1998; Nybo and Nielsen, 2001; Tucker *et al.,* 2004) whereby empirical data is evident within table 2.1.

Table 2.1: Reductions in central activation in cross-sectional studies (Abiss and Lauresen, 2005)

Study	Protocol Duration	Muscle	Reduction in Central Activation	Reduction in $RMS/RMSS_m$ (%)
Lepers *et al.,* (2000)	30-min	VL & VM	16.1	13.9
Lepers *et al.,* (2001)	2hours	VL & VM	24.2	30.0
Lepers *et al.,* (2002)	5hours	VL	8.5	30.0

*Summary of studies that have measured the fatiguability of skeletal muscle during prolonged sub maximal cycling. A reduction in $RMS/RMSS_m$ suggests an impairment to central activation (Lepers *et al.,* 2002; Lepers *et al.,* 2001). RMS = root mean square; $RMSS_m$ = root mean square (M-wave); VL = vastus lateralis; VM = vastus medialis

Despite hyperthermia-induced central fatigue being primarily associated with inhibitory signal from thermoreceptors (Nybo, 2008), a link with cerebral metabolism and oxygen delivery has been identified (Secher *et al.,* 2008). Reductions in both arterial carbon dioxide pressure (Nybo *et al.,* 2002; Kayser, 2003) and cerebral blood flow (Nybo, 2008) occur as respiratory rate increases to meet $\dot{V}O_2$ demand (Nybo and Nielsen, 2001). Consequently, motor function declines as oxygenation levels decrease (Nybo and Rasmussen, 2007; Rasmussen *et al.,* 2007) via reductions in cerebral substrate supply and waste removal (Gray and Nimmo, 2001; Kay *et al.,* 2001). However, reductions in cerebral blood flow fail to explain hyperthermia-induced central fatigue within laboratory conditions as exercise is terminated prior to this point (Nybo, 2008). Alternatively, competition requirements may go beyond this point, which makes cerebral blood flow an issue relating to central fatigue during any performance related research (Nybo *et al.,* 2002).

Overall, hyperthermia induced central fatigue originates primarily from the ability to maintain sufficient activation of skeletal muscle. Reductions in cerebral blood flow fail to restrict substrate supply to critical levels whereby cerebral temperature and sensory feedback become the primary factors affecting motor activation (Nybo, 2008). However, hyperthermia-induced central fatigue is not an all or nothing phenomenon that occurs exclusively with elevated cerebral temperature. A progressive inhibition of cerebral signals (Nybo, 2008), reductions in neural drive and alterations in cerebral perfusion/substrate supply all contribute to the central fatigue process (Morrison *et al.*, 2004).

2.2.4: Critical Core Temperature

Despite associating fatigue with alterations in muscle metabolism, CNS function (Hasegawa *et al.*, 2005) and/or cardiovascular failure (Galloway and Maughan, 1997) several researchers identified that fatigue is dictated by both brain and hypothalamic temperature (Cheung and McLellan, 1998) which occurs when a critical T_c is reached (>39.5 °C) (Nielsen *et al.*, 1993; Cheung and McLellan, 1998; Gonzalez-Alonso *et al.*, 1999; Hasegawa *et al.*, 2005). This concept was primarily proposed by Nielsen *et al.*, (1993) who demonstrated that heat acclimation increased exercise duration (40%) despite voluntary exhaustion still occurring at a similar T_c (~39.7 °C). Supportive evidence reports that during self-paced performance athletes progressively decreased exercise intensity to ensure the maintenance a T_c below critical limits (Tatterson *et al.*, 2000). The potential mechanisms for this fatigue relate to the aforementioned reductions in the central activation of skeletal muscle (Nybo and Nielsen, 2001) and cerebral blood flow (Nybo and Nielsen, 2003).

Any critical T_c is athlete specific and primarily influenced by aerobic fitness ($\dot{V}O_{2max}$) as athletes with higher levels of aerobic fitness tolerate higher levels of hyperthermia (Cheung *et al.*, 1998). However, inconsistencies relating to varied T_c assessments, exercise protocols, and environmental conditions mean empirical data becomes incomparable. Therefore, despite evidence suggesting a potential point when the human body will terminate exercise to ensure personal safety, any accurate critical T_c value is impossible to determine due to its highly individualised nature. Consequently, additional research may be necessary to further justify the acceptance of this critical T_c theory and its role within the hyperthermia-induced fatigue process.

Fatigue is a complex process and throughout sub maximal exercise within hot environments it is determined by a delicate interplay between factors of both central and peripheral origin (Nybo, 2008). Researchers must accept that a combination of CNS decline, variations in blood flow and critical T_c levels all contribute to the early onset of fatigue (Gonzalez-Alonso *et al.,* 1999; Kay *et al.,* 2001; Nybo *et al.,* 2001; Tucker *et al.,* 2004; Watson *et al.,* 2005; Tucker *et al.,* 2006). The role of each fatigue process must be appreciated to enable the development of current and/or new strategies to provide any thermoregulatory and physiological advantage during sub maximal exercise in the heat.

2.3: Optimising Performance and Thermoregulation in Hot Environments

2.3.1: Heat Acclimation

Acclimation is the process when an athlete adapts to competition conditions through training in a simulated environment (Maughan and Shirreffs, 2004). A similar approach, termed acclimatisation, is when an athlete both lives and trains in a climate similar to that of the competition venue (Maughan and Shirreffs, 2004). Heat acclimatisation has no significant advantage over heat acclimation when adequate protocols are prescribed (Montain *et al.,* 1996).

Heat acclimation improves thermoregulation (Maughan and Shirreffs, 2004; Saat *et al.,* 2005) and reduces pre-exercise T_c (Nielsen *et al.,* 1993; Buono *et al.,* 1998) through various metabolic, biochemical, haematological and cardiovascular adaptations (Armstrong, 2000). Preliminary adaptations improve cardiovascular function (Reilly *et al.,* 2006) and minimise variations in blood flow by maintaining blood pressure regulation and increasing plasma volume (Patterson *et al.*, 2004). Longitudinal adaptations include reductions in thermoregulatory thresholds and further improvements to thermoregulation via alterations to both sweat gland function and the sodium and chloride re-absorption process (Taylor and Cotter, 2006). Heat acclimation improves both T_c and HR responses to exercise whilst increases in plasma volume maintains cardiac output for an extended exercise duration whereby no significant reductions in muscle blood flow, variations in substrate utilisation or accumulated fatigue substances were evident upon fatigue (Nielsen *et al.,* 1993). This suggests that by improving thermoregulation, heat acclimation provides a physiological advantage through minimising variations in circulation and allowing adequate muscle and peripheral blood flow to be maintained for an extended duration (Nielsen *et al.,* 1993; Buono *et al.,* 1998).

The success of any heat acclimation protocol and the extent of each adaptation is dependent upon the magnitude of T_c elevation and the scale of the thermoregulatory response imposed (Maughan and Shirreffs, 2004). The proposed adaptations occur only when sufficient thermal stress is induced and adequate exercise intensity (>60% $\dot{V}O_{2max}$) and time scales (>7 days) are prescribed (Montain *et al.,* 1996). Therefore, despite the aforementioned advantages of heat acclimation the limitations described above represent why this strategy is rarely used by non-elite athletes and those with limited inter-competition time scales. Consequently, it becomes imperative to evaluate more practical interventions to improve sub maximal performance and decrease environmental impact.

2.3.2: Pre Performance Cooling

Pre performance cooling delays variations in blood flow and increases the margin for metabolic heat production by reducing both T_c and T_{sk} before competition (Marino, 2002). Numerous protocols have been identified to promote both local (ice packs) and systemic (water immersion) reductions in T_c (Booth *et al.*, 2001; Duffield *et al.*, 2003; Arngrimsson *et al.*, 2004; Hasegawa *et al.*, 2006). Pre performance cooling reduces sweat rate as the reduction in T_{sk} increases the thermal gradient for convective heat loss (Kay *et al.*, 1999). Reductions in T_{sk} delay the variations in blood flow associated with fatigue (Duffield *et al.*, 2003) as peripheral blood flow demand decreases whilst the preservation of body water increases the blood volume available for heat dissipation (Lee and Haymes, 2005). Pre performance cooling increases heat storage whilst decreasing elevations in HR (Hasegawa *et al.*, 2006) as a greater margin for metabolic heat production is available without compromising cardiovascular dynamics (Kay *et al.*, 1999). Supportive evidence reports that despite similar HR responses in both conditions (pre performance cooling vs. control) higher intensities were maintained in the pre performance cooling trial, indicating higher intensities are sustainable for similar HR responses (Kay *et al.*, 1999). These physiological advantages are predominantly a result of reductions in CNS decline alongside the improved ability to maintain both peripheral and muscle blood flow demands (Arngrimsson *et al.*, 2004; Castle *et al.*, 2006; Reilly *et al.*, 2006). A summary of research into pre performance cooling and its effect on performance and both thermoregulatory and physiological responses to exercise is available in table 2.2.

Table 2.2: Summary of research evaluating pre performance cooling, performance and thermoregulation (Hasegawa *et al.*, 2008).

Study	Participants	PPC Method	Protocol	Environmental Conditions	Results
Gonzalez-Alonso *et al.*, (1999)	7	Water immersion (30min)	Cycling to exhaustion (60% $\dot{V}O_{2max}$ VO_{2max})	40 °C, 19% RH	↑ TTE ↓ T_{es}, T_{sk}, HR
Booth *et al.*, (2001)	7	52-min water immersion (29-24 °C)	35 min cycling trial (60%VO_{2max})	35 °C, 50% RH	↓ T_{es}, T_{mus} → Muscle metabolism (creatine, lactate, glycogen, creatine phosphate)
Duffield *et al.*, (2003)	7	Ice jacket	80 min Intermittent cycling exercise	30 °C, 60% RH	→ Power Output → T_{re}, T_{sk}, HR, RPE, lactate, Sweat loss ↓Thermal discomfort
Arngrimsson *et al.*, (2004)	17	Cooling vest during warm-up	5-km simulated running	32 °C, 50% RH	↑ Exercise performance
Hayashi *et al.*, (2004)	7	Leg-cooling (20 °C) via water immersion	50 min cycling (65%VO_{2max})	35 °C, 50% RH	↓ T_{es}, T_{sk}, HR, VO_2, → RPE, lactate
Hasegawa *et al.*, (2005)	9	Cooling vest during warm-up and 60 min of exercise	60 min Cycling (60%VO_{2max}) and 80%VO_{2max} to exhaustion	32 °C, 80% RH	↑ TTE ↓ T_{re}, T_{sk}, HR, HS, sweat loss
Hsu *et al.*, (2005)	11	AVA core device	Study 1: 60-min Cycling (60%VO_{2max}) Study2: Two 30-km cycling trial	32 °C, 24% RH	Study 1: ↓ T_{ty}, VO_2, lactate Study 2: ↑ Exercise performance; ↓ T_{ty}
Hasegawa *et al.*, (2006)	9	30 min water immersion (25 °C)	60 min cycling (60%VO_{2max}) and 80%VO_{2max} to exhaustion	32 °C, 80% RH	↑ TTE ↓ T_{re}, T_{sk}, HR, HS, sweat loss,

HR = Heart Rate; **HS** = Heat Storage; **RPE** = Rating of percieved exertion; **TTE** = Time to Exhaustion; **RH** = relative humidity; $\mathbf{T_{es}}$ = Esophageal temperature; $\mathbf{T_{re}}$ = Rectal Temperature; $\mathbf{T_{sk}}$ = mean skin temperature; $\mathbf{T_{ty}}$ = Tympanic temperature; ↑ indicate increase; ↓ indicate decrease; → indicates no effect

The aforementioned advantages of pre performance cooling seen within table 2.2 are well documented (Arngrimsson *et al.,* 2004; Hasegawa *et al.,* 2005; Hsu *et al.,* 2005). However, despite these advantages pre performance cooling lacks practical utility to many athletes due to strict pre competition time scales and regulations (Marino, 2002). Additionally, some authors may argue that pre performance cooling potentially inhibits the advantages gained via an active warm-up (Hunter *et al.,* 2006) whilst any advantage will have minimal effect if thermoregulation is inhibited by inappropriate clothing (Kwon *et al.,* 1998, Gavin, 2003). Consequently, further research is warranted into more logistical interventions that are easily applicable to athletes regardless of competition regulations or performance requirements.

2.4: Clothing and Sub Maximal Exercise

Clothing impedes thermoregulation by restricting evaporative heat loss (Robert *et al.,* 2007) whereby the clothing that poses the smallest barrier to evaporative heat loss potentially improves thermoregulation (Kwon *et al.,* 1998; Gavin, 2003). Dependant on textile construction, clothing can significantly affect both physiological and thermoregulatory responses to exercise (Kwon *et al.,* 1998; Gavin, 2003; Morgan and Shirreffs, 2004; Roberts *et al.,* 2007). Consequently, research into clothing and thermoregulation during sub maximal exercise has received increased attention in recent years (Gavin *et al.,* 2001; Gavin, 2003; Roberts *et al.,* 2007) as it offers a practical way to minimise environmental impact during exercise.

Kwon *et al.,* (1998) investigated thermoregulatory responses to three different clothing textiles (wool/cotton blend, 100% cotton and 100% polyester) during intermittent exercise. Throughout exercise the wool/cotton blend significantly reduced T_c whilst polyester demonstrated a significantly higher T_{sk} and HR when compared to all other fabrics (Kwon *et al.,* 1998). The

100% polyester fabric increased sweat rate but its minimal wicking capability decreased the amount of heat lost per gram of sweat. Kwon *et al.,* (1998) concluded that compared to the other traditional fabrics cotton posed the smallest barrier to evaporative heat loss and potentially improved thermoregulation. Meir *et al.,* (1994) investigated thermoregulatory responses to game-play rugby t-shirts (alternative lightweight vs. game-play) during a 50 minute sub maximal running protocol (50% $\dot{V}O_{2max}$). Despite no significant difference in T_c, conclusions derived that the innovative construction and improved wicking capabilities of the alternative lightweight garment potentially improved thermoregulation. These advances in textile technology lead to the development of specialised under garments, termed base layers, that potentially improve thermoregulation by maximising evaporative heat loss through superior wicking and regain capabilities (Gavin *et al.,* 2001; Adidas, 2009; Skins, 2009).

2.5: Base Layers

2.5.1: Development and Purpose

Base layers are constructed to optimise evaporative heat loss through superior wicking and regain properties (Roberts *et al.,* 2007). The physical characteristics of a base layer, identified within table 2.3, highlight their contrast when compared to a traditional fabric.

Table 2.3: Physical Properties of a Base Layer (Roberts *et al.*, 2007)

Garment	Yarn Height (mm)	Yarn Width (mm)	Number of Courses	Interstice Length (mm)	Interstice Width (mm)
Base Layer	0.65 ± 0.02^a	0.17 ± 0.01^a	21^a	0.17 ± 0.04^a	0.08 ± 0.01^a
Cotton	1.19 ± 0.12	0.31 ± 0.02	9	0.11 ± 0.02	0.06 ± 0.01

*Values expressed as mean ± SD. Garment properties produced through analysis of a 5 mm by 5 mm section of each garment through an optical measuring device at 288x magnification. Base Layer represents Canterbury of New Zealand base layer garment. Number of courses represents the number of horizontal loops across the width of the fabric (Apparel Research, 2009); Interstice represents the gap between adjacent fibres. [a] denotes significantly different from cotton ($P < 0.05$).

The larger interstices and smaller yarn size within the base layer increase the airflow within the microenvironment created by the garment (Houdas and Ring, 1982) whilst the reduction in garment thickness and the low moisture absorbency properties create superior wicking and regain capabilities. These properties are purported to provide a physiological advantage by minimising increases in both T_{sk} and T_c during exercise in hot environments (Adidas, 2009; Skins, 2009a). However, despite their widespread use (Houghton *et al.,* 2009) only two studies have evaluated base layers during sub maximal exercise and both fail to support any physiological advantage (Gavin *et al.,* 2001; Roberts *et al.,* 2007).

2.5.2: Base layers and Sub Maximal Exercise

The first piece of research was conducted by Gavin *et al.,* (2001) who investigated thermoregulatory and physiological responses to three garments (base layer, cotton and lycra swimsuit). Experimental trials consisted of 20 minutes seated rest followed by 30 minutes of treadmill running (70% $\dot{V}O_{2max}$) and 15 minutes of walking (40% $\dot{V}O_{2max}$) all within hot environmental conditions (30 ± 1 °C, 35 ± 5% RH). Base layers significantly reduced the respiratory exchange ratio (RER) and carbon dioxide output ($\dot{V}CO_2$) during the walking phase as substrate utilisation improved (Gavin *et al.,* 2001). No significant differences in T_c, T_{sk}, $\dot{V}O_2$, HR, S_{Loss}, thermal comfort or sweating sensations were reported during any phase (base layer vs. cotton). Despite no significant difference in sweat loss base layers significantly improved evaporative efficiency and clothing regain as cotton retained three times the amount of sweat. This suggests that the improvements to evaporative efficiency failed to reach the extent required to significantly alter either T_c or T_{sk}. Gavin *et al.,* (2001) concluded that that both during and after exercise base layers failed to significantly alter physiological or thermoregulatory responses.

The second piece of research (Roberts *et al.,* 2007) examined the relationship between base layers and thermoregulation during an intermittent exercise protocol (Drust *et al.,* 2000) within cool environmental conditions (20 °C; 47% RH), the results of which can be seen in table 2.4.

Table 2.4: Summary of Results reported by Roberts *et al.,* (2007)

	Base Layer	Cotton
Mean Skin Temperature (°C)	29.1 ± 0.4^a	29.8 ± 0.8
Core Temperature (°C)	37.9 ± 0.3	38.0 ± 0.3
RPE (Borg, 1982)	11.9 ± 1.2	11.8 ± 1.2
Comfort (Bedford, 1936)	8.1 ± 0.7^a	9.4 ± 0.6
Thermal Comfort (ASHRAE, 1966)	8.3 ± 0.6^a	9.7 ± 0.7
Moisture Retention (kg)	0.04 ± 0.03^a	0.07 ± 0.04
Rate of Evaporation ($ml \cdot hr^{-1}$)	28 ± 15^a	40 ± 13

*Values expressed as mean ± SD; Moisture evaporation shown as garment mass increase; Rate of evaporation was calculated by hanging the garment within experimental conditions for 45 minutes; [a] denotes significantly different that cotton ($P < 0.05$)

Roberts *et al.,* (2007) proposed that the superior evaporative and moisture retention qualities of the base layer significantly reduced mean T_{sk} which translated into the significant improvement in athlete comfort. However, reductions in mean T_{sk} failed to reach the extent required to reduce either RPE or T_c whilst any physiological effect ($\dot{V}O_2$, HR, etc) is unknown as this data was not collected. Roberts *et al.,* (2007) concluded that base layers are superior to 100% cotton garments with respect to thermoregulation and athlete comfort as they successfully permitted the body to remain close to bare-chested temperatures during exercise.

Finally, a pilot study (see section 3.1: Pilot Study) was conducted at the University of Gloucestershire to further understand base layer research prior to the present investigation. Dymond (2008, unpublished) reported significant differences in S_{Loss} and T_{sk} ($P < 0.001$) whilst no other significant difference were detected in T_c, HR, $\dot{V}O_2$ or RPE (base layer vs. cotton). Dymond (2008, unpublished) concluded that significant increases in S_{Loss} translated into a significant reduction in mean T_{sk}, as seen in Roberts *et al.,* (2007). However, after 30 minutes of exercise mean T_c in the base layer trial elevated above that experienced within the cotton trial (38.7 vs. 38 °C). Dymond (2008, unpublished) concluded that the saturation of the base layer achieved through the combination of an increased sweat rate and prolonged exercise duration inhibited thermoregulation to the extent that a rapid increase in T_c occurred. Overall, the pilot investigation revealed the capacity for base layers to potentially become saturated when excessive sweat rates combine with prolonged exercise durations.

Research accepts that base layers potentially improve thermoregulation by improving evaporative heat loss through their superior wicking and moisture retention properties (Gavin *et al.,* 2001; Roberts *et al.,* 2007). Base layer research has produced conflicting results whereby no reports of any physiological advantage or T_c reduction is evident. Alternatively, data suggests potential advantages may manifest within certain conditions and/or exercise intensities when thermal stress is adequate to induce thermoregulatory responses. However, despite both Gavin *et al.,* (2001) and Roberts *et al.,* (2007) supplementing knowledge upon base layers, numerous limitations regarding experimental protocol, research design and practical application require evaluation prior to the acceptance or development of further research.

2.5.3: Critique of Base Layer Research

The primary issues regarding both Roberts *et al.,* (2007) and Gavin *et al.,* (2001) surround the exercise duration, environmental conditions and the resulting thermal stress of exercise. Data presented within both investigations shows a failure to induce sufficient thermal stress as maximum mean T_c remained within optimal limits (≤38.2 °C). This suggests both investigations failed to produce valid research into the effect of base layers on thermoregulatory and physiological responses to exercise as any potential advantage gained from the superior wicking and regain properties would have been negated. Inadequate thermal stress primarily resulted from the exclusion of external heat within Roberts *et al.,* (2007) whilst Gavin *et al.,* (2001) failed to extend exercise duration beyond the point when thermoregulation significantly affects blood flow, muscle metabolism and $\dot{V}O_2$ during sub maximal exercise within hot environments (Gonzalez-Alonso *et al.,* 1998, 1998). Consequently, both investigations minimised the likelihood of detecting any significant differences as the failure to elevate T_c beyond optimal limits would have failed to induce any of the aforementioned variations associated with hyperthermia-induced fatigue.

Secondly, issues surrounding the collection and interpretation of metabolic data are evident within Gavin *et al.,* (2001) as metabolic data collection terminated after only 10 minutes of the exercise phase despite exercise continuing for a further 20 minutes. Although athletes reach steady state $\dot{V}O_2$ within 4 minutes (Morgan *et al.,* 1989) this is not the case during exercise in hot environmental conditions as variations in expired air continue throughout exercise since $\dot{V}O_2$ is modulated by various factors influenced by T_c (Kaufman, 1995; Piepoli *et al.,* 1995; Gonzalez-Alonso *et al.,* 1999; Hayashi, 2006). Therefore, when metabolic data collection terminated, $\dot{V}O_2$, RER and $\dot{V}CO_2$ may have continued to vary as graphical representation shows that T_c continued to elevate beyond the 10 minute point of the exercise phase. Therefore, the suggested improvements to substrate utilisation, identified by a significant decline in both RER and $\dot{V}CO_2$, was based on limited data and did not represent the whole exercise phase. Additionally, independent of substrate utilisation, differences in RER may have resulted from varying pre exercise diets and/or intramuscular temperatures (Gavin *et al.,* 2001). However, these factors were not taken into account within the research which suggests that the metabolic data within Gavin *et al.,* (2001) was unrepresentative of the real energy cost and subsequently failed to accurately represent the true effect of the base layer.

Finally, issues relating to the statistical analysis within Roberts *et al.,* (2007) must be evaluated. The combination of sample size (n = 7), garment variation (4) and inappropriate statistical analysis minimised the likelihood of detecting any significant differences in the sensitive thermoregulatory variables investigated. Justification develops from both the power analysis on the pilot data (see 2.1.3: Data Analysis) and the numerous levels created within the analysis of T_c as samples were taken every 30-sec throughout the 47 minute intermittent protocol (Roberts *et al.,* 2007). Additionally, Roberts *et al.,* (2007) failed to investigate any interaction effect (garment x time) or any main effect for time or condition as analysis consisted of only Student paired T-tests performed in Microsoft Excel®. Therefore, any conclusions reported by Roberts *et al.,* (2007) are based on weak statistical analysis whereby further understanding of statistics justifies that inadequate statistical power may be a potential issue relating to the likelihood of type II errors (Thomas *et al.,* 1991), an issue that was not addressed by Roberts *et al.,* (2007).

Overall, both Gavin *et al.,* (2001) and Roberts *et al.,* (2007) failed to implement either adequate exercise protocols, environmental conditions or statistical analysis to produce valid research conclusions in relation to base layers and both thermoregulatory and physiological responses to exercise. Consequently, research has failed to evaluate the true effects of base layers whilst also failing to either investigate them during adequate environmental conditions or exercise duration where their superior physical properties are able to manifest any advantage.

2.6: Summary

Research identifies that a delicate interplay between both peripheral and central fatigue factors induces the early onset of fatigue during sub maximal exercise within hot environments. Evidence shows thermoregulation becomes a key limiting factor of performance as variations in blood flow, muscle metabolism and CNS function occur when an optimal thermal state is lost. Interventions such as pre performance cooling and heat acclimation have been identified to improve thermoregulation and provide a physiological advantage during sub maximal exercise within hot environments. However, it was suggested that both interventions lack practical utility to non elite athletes and those with limited inter-competition time scales whilst clothing was identified as a more practical strategy.

Advances in textile technology identified that, dependant on textile construction; clothing can improve both thermoregulatory and physiological responses to exercise (Kwon *et al.,* 1998, Gavin 2003). These advances prompted the construction of specialised under garments, termed base layers, which potentially improve thermoregulation and provide a physiological advantage by optimising evaporative heat loss. Despite base layers improving supra-maximal exercise (Kraemer *et al.*, 1996; Doan *et al.*, 2003) and recovery (Berry *et al.*, 1990; Duffield and Portus, 2007) research into sub maximal exercise reports conflicting findings with no physiological advantages reported to date. However, a review of literature highlights that base layer research failed to simulate the true physiological demands of sub maximal exercise within hot environmental conditions to the extent whereby any advantage provided by the base layer was potentially negated. Consequently, issues surrounding whether base layers provide any advantage during sub maximal exercise is unresolved whilst their application within varied environmental conditions has yet to be interrogated. As their use continues to increase further evaluation in relation to the true physiological demands of sub maximal exercise in varied environmental conditions is necessary to determine if any advantage is provided and within which environments they manifest.

2.7: Hypotheses

H_1: Wearing a base layer during sub maximal continuous exercise (60% $\dot{V}O_{2max}$) in ambient environmental conditions (20°C; 35% RH) significantly effects either T_c, T_{sk}, $\dot{V}O_2$, HR, RPE or comfort sensations when compared to a cotton based garment.

H_2: Wearing a base layer during sub maximal continuous exercise (60% $\dot{V}O_{2max}$) in hot-dry environmental conditions (30°C; 35% RH) significantly effects either T_c, T_{sk}, $\dot{V}O_2$, HR, RPE or comfort sensations when compared to a cotton based garment.

H_3: Wearing a base layer during sub maximal continuous exercise (60% $\dot{V}O_{2max}$) in hot-humid environmental conditions (30°C; 80% RH) significantly effects either T_c, T_{sk}, $\dot{V}O_2$, HR, RPE or comfort sensations when compared to a cotton based garment.

CHAPTER III

PILOT STUDY

3.1: Aims and Objectives

Given the limited availability of base layer research a pilot study was conducted prior to the main investigation. The aim of the pilot study was to assess the necessary sample size and both the exercise duration and intensity required to adequately examine the efficacy of a base layer. The pilot study was also used to highlight any potential issues that may require further research within the main investigation. Conclusions from the pilot study would then form the basis to construct a valid and reliable methodology allowing the main research to fully interrogate if, when compared cotton, any advantage manifests when wearing a base layer garment.

3.2: Method

3.2.1: Participants

Eight healthy males (mean ± SD; age 20 ± 1 yr, stature 1.77 ± 0.05m, body mass 76.3 ± 9.2kg; $\dot{V}O_{2max}$ 52.8 ± 7.2ml·kg^{-1}·min^{-1}) from the University of Gloucestershire soccer team volunteered for the pilot investigation. Participants were informed of both the aims and potential risks before completing written informed consent (Appendix I) and a health questionnaire (Appendix II), upon which all were deemed eligible. All protocols employed had been previously approved by The University of Gloucestershire Research Ethics Committee and were in line with the laboratory procedures manual (University of Gloucestershire, 2008).

3.2.2: Preliminary Testing to Determine Maximal Aerobic Power

A preliminary test to determine $\dot{V}O_{2max}$ was completed within an environmental chamber maintained at 30 °C and 65% RH. Participants attached a heart rate monitor (Vantage Polar, Kempele, Finland) around their chest before starting a three minute self paced warm up whereby the test started immediately upon completion. Participants ran on a motorised treadmill (ELG 55, Woodway Gmbh, Weil am Rhein, Germany) at $8km \cdot h^{-1}$ on a 0% incline whereby treadmill speed was progressively increased every 8-s ($0.16km \cdot h^{-1}$). The test was terminated upon reaching volitional fatigue, defined as the inability to maintain the required running speed, upon which participants used the safety rails to lift themselves off the treadmill. Four minutes into the protocol 30-s samples of expired air were collected every minute until the termination of the test. Both collection and analysis of expired air was completed according to procedures detailed within the main research. Calculated values for $\dot{V}O_2$ were plotted against mean speed for each 30-s stage whereby linear regression determined the speed required to elicit the pilot trial intensity (60% $\dot{V}O_{2max}$). In the absence of a $\dot{V}O_2$ plateau, $\dot{V}O_{2max}$ was recorded as the highest $\dot{V}O_2$ observed at any time providing the participant attained at least two of the secondary criteria detailed later within 3.2.4: Preliminary Test to Determine Maximal Aerobic Power (pg 39).

3.2.3: Pilot Trials

Participants completed a three minute warm up at $8km \cdot h^{-1}$ on a 0% incline prior to attaching all the necessary equipment described within the main research. Participants completed two 40 minute sub maximal (60% $\dot{V}O_{2max}$) running protocols on a motorised treadmill (ELG 55, Woodway Gmbh, Weil am Rhein, Germany) within hot-humid conditions (30 °C; 65% RH). Participants wore running trainers, cotton shorts and socks alongside either a 100% cotton crew neck or a base layer t-shirt (Adidas, 2009). Protocols were completed in a crossover repeated measures design and separated by 2-5 days to eliminate fatigue (Burnley *et al.,* 2001). Each protocol was completed at the same time of day to control circadian variation (Reilly and Brooks, 1986; Waterhouse *et al.,* 1999). Throughout each protocol fluid intake was prohibited and participants abstained from caffeine, alcohol or any physical activity 24 hours before each trial. Values for body temperature, T_c and T_{sk} were recorded at base line, 10, 30 and 40 minutes whilst HR, $\dot{V}O_2$ and RPE were recorded at only 10, 30 and 40 minutes. Body temperature was calculated by equation 2 whilst all other variables, including S_{Loss}, were recorded and calculated according to procedures outlined within the main research.

$$\text{Body Temperature} = (0.65 * T_c) + (0.35 * T_{sk}) \quad \text{...(2)}$$

(Ramanthan, 1964)

3.2.4: Data Analysis

Data were analysed in SPSS for Windows (SPSS Inc, version 14, Chicago, Ill). Repeated measures analyses of variance (ANOVA; 2x4, garment x time) and a paired sampled t-test analysed any differences between garments in T_{body}, T_{sk}, HR, $\dot{V}O_2$, RPE and S_{Loss} respectively. Where significant main effects were detected Bonferroni corrected t-tests were employed to further explore any differences. The level of significance was set at $P < 0.05$. Power analysis was conducted on mean values for T_c whereby figures for effect size, the number of tails and desired power were used to calculate the sample size necessary to produce adequate statistical power within the main research.

3.3: Results

3.3.1: Body Temperature

Repeated measures ANOVA showed a significant interaction effect (garment x time; $P = 0.03$) and a significant main effect for time on T_{body} ($P < 0.001$). Pairwise comparisons and Bonferroni corrected t-tests revealed significant differences between garments at all time points except 0 ($P = 0.312$) and 40 minutes ($P = 0.233$). Values for mean T_{body} can be seen in Figure 3.1.

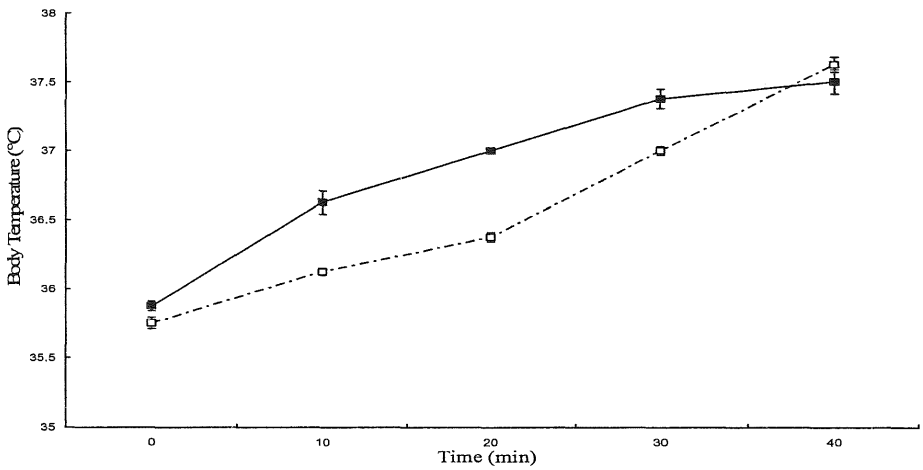

Figure 3.1: Change in T_{body} during pilot trials. Values show as mean ± SE.(■)= cotton; (□)= base layer.

3.3.2: Mean Skin Temperature

Repeated measures ANOVA revealed a significant interaction effect (garment x time; $P < 0.001$) and a main effect for time on T_{sk} ($P < 0.001$). Pairwise comparisons and Bonferroni corrected t-tests revealed significant differences between garments at all time points except 0 ($P = 0.192$) and 40 minutes ($P = 1.00$). Values for mean T_{sk} can be seen in Figure 3.2.

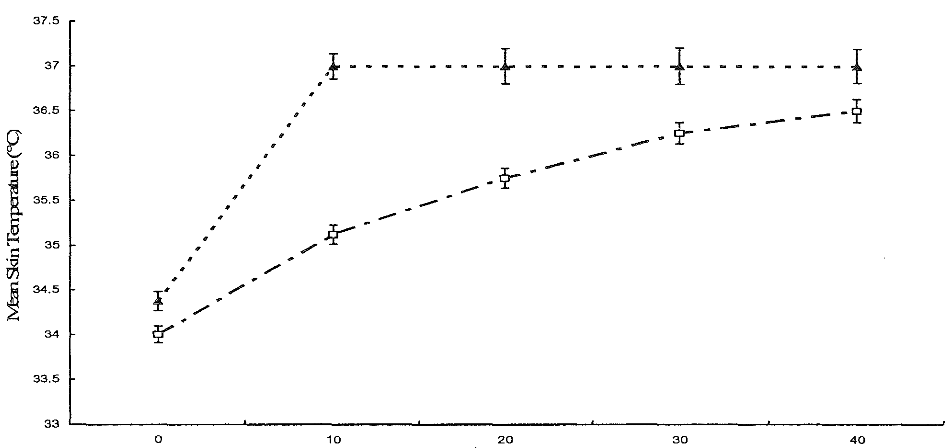

Figure 3.2: Change in T_{sk} during pilot trials. Values shown as mean ± SE. (■) = cotton; (□) = base layer.

3.3.3: Oxygen Uptake

Repeated measures ANOVA showed no significant interaction effect (garment x time; P = 0.095) whilst a main effect for time (P <0.001) was detected on $\dot{V}O_2$. Pairwise comparisons and Bonferroni corrected t-tests showed significant differences between 15 to 40 (P = 0.023) and 30 to 40 minutes only (P = 0.036). No significant differences between garments were detected at any time point. Mean values for $\dot{V}O_2$ can be seen in figure 3.3.

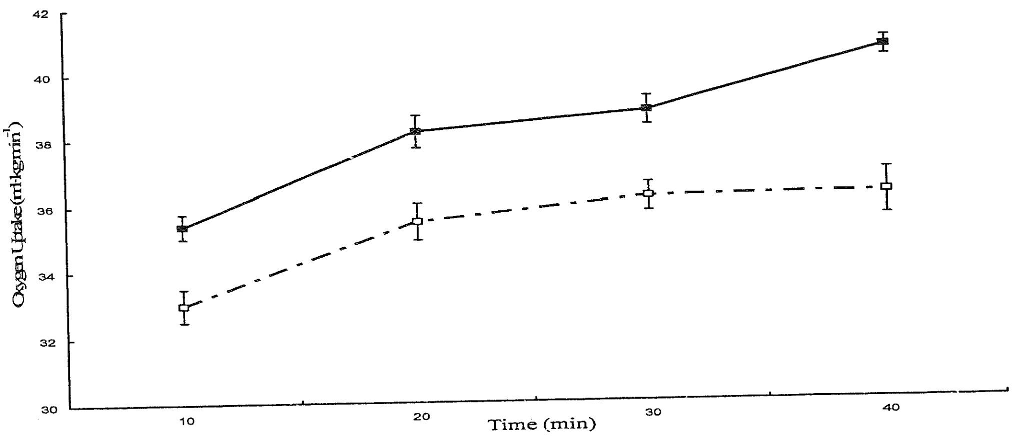

Figure 3.3: Change in $\dot{V}O_2$ during pilot trials. Values shown as mean± SE. (■) = cotton; (□) = base layer.

3.3.4: Heart Rate

Repeated measures ANOVA showed no significant interaction effect (garment x time; P = 0.575) whilst a significant main effect for time was detected on HR (P < 0.001). Pairwise comparisons and Bonferroni corrected t-tests revealed a significant difference between 20 and 40 minutes only (P = 0.009). Mean values for HR can be seen in figure 3.4.

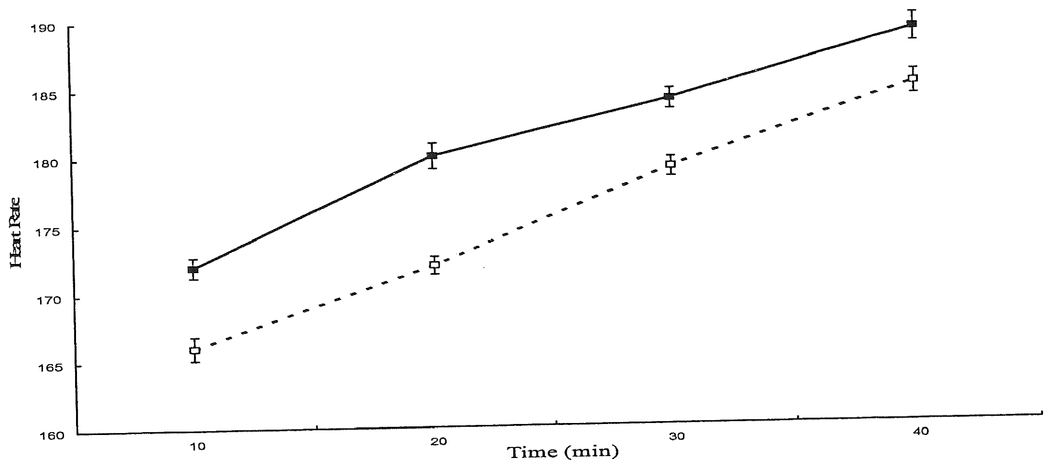

Figure 3.4: Change in HR during pilot trials. Values shown as mean ± SE. (■) = cotton; (□) = base layer

3.3.5: Rating of Perceived Exertion

Repeated measures ANOVA showed no significant interaction effect (garment x time; $P = 0.498$) whilst a main effect for time was detected on RPE ($P < 0.001$). Pairwise comparisons and Bonferroni corrected t-tests revealed significant differences between 10 to 20 ($P = 0.005$) and 20 to 30 minutes ($P = 0.031$) only. Mean values for RPE can be seen in figure 3.5.

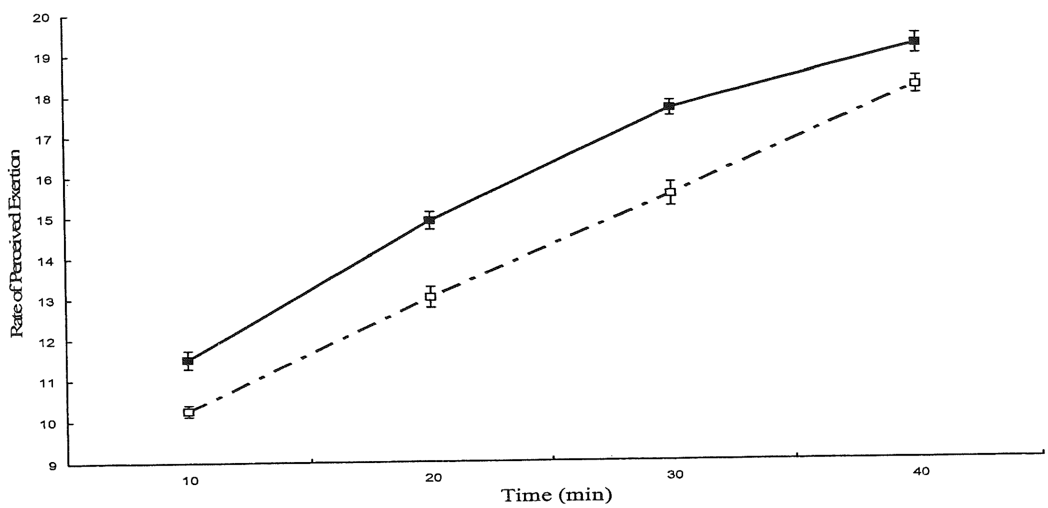

Figure 3.5: Change in RPE during pilot trials. Values shown as mean ± SE. (■) = cotton; (□) = base layer.

3.3.6: Estimated Sweat Loss

A paired samples t-test revealed a significant difference in S_{Loss} between garments ($P < 0.001$). Mean values for S_{Loss} can be seen in figure 3.6.

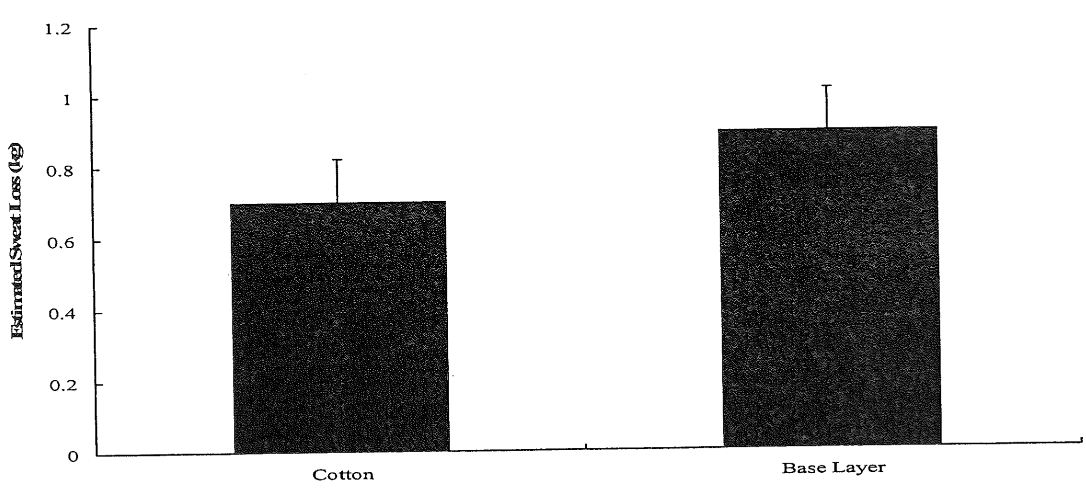

Figure 3.6: Estimated sweat loss for each pilot trial. Values shown as mean ± SD (kg).

3.4: Discussion

3.4.1: Key Findings

Thermoregulatory responses to sub maximal exercise were significantly improved when a base layer was worn during exercise within hot environmental conditions. Significant interactions (garment x time) for both T_{sk} and T_{body} were detected whereby post-hoc analysis revealed significant differences between garments for both T_{sk} and T_{body} at all time points except 0 and 40 minutes. This indicates that, when compared to cotton, the base layer worked more effectively at reducing elevations in both T_{sk} and T_{body} which shows that there may be a potential thermoregulatory advantage to be gained. Paired sample t-tests revealed a significant difference in S_{Loss}, indicating that the base layer significantly increased the amount of sweat lost throughout exercise. No other significant interactions between garments were detected at any time point. Power analysis on mean T_c responses determined that a sample size of 12 was necessary to produce the desired statistical power within the main research. In line with Roberts *et al.,* (2007) the base layer provided a thermoregulatory advantage during sub maximal exercise.

3.4.2: Explanation of Results

During sub maximal exercise within a hot environment the rate at which T_{body} increases is primarily determined by evaporative heat loss whereby evaporative heat loss has a positive relationship with sweat rate/S_{Loss} (Hasegawa *et al.,* 2005; Wendt *et al.,* 2007). With this in mind it suggests that the significantly elevated S_{Loss} within the base layer trial potentially increased evaporative heat loss, thus lowering both T_{body} and T_{sk} when compared to cotton. This potentially lower rate of heat storage decreases the extent to which thermoregulation effects the onset of fatigue as the negative effects of competing blood flow demands, central fatigue mechanisms and dehydration become less pronounced. This evidence shows that, when compared to cotton, the base layer provides a thermoregulatory advantage which could potentially translate into a performance advantage. However, as no performance measures were taken these claims remains speculative and require further research.

Post hoc analysis revealed significant differences in T_{body} between garments at all time points except 0 (P = 0.312) and 40 minutes (P = 0.233). This indicates that, when compared to cotton, the base layer worked more effectively at reducing elevations in T_{body} until peak exercise whereby at this point T_{body} was no longer significantly lower within the base layer trial. This provides significant findings as T_{body} was statistically lower during exercise despite starting and ending at similar temperatures. An explanation to this finding is highlighted within figure 3.1 which reveals that the previously mention thermoregulatory advantage was only apparent until the 20 minute collection point. Beyond this point T_{body} in the base layer trial increased at a rate superior to that experienced in the cotton trial whereby at peak exercise T_{body} was higher within the base layer trial (37.7 vs. 37.6°C). This highlights that, when compared to cotton, a base layer provides a thermoregulatory advantage during the early stages of exercise whereby detrimental effects may manifest as exercise duration exceeds 20 minutes. A potential explanation for this finding relates back to the S_{Loss} experienced within the base layer trial. The elevated S_{Loss} may have lead to the saturation of the base layer causing a reduction in evaporative heat loss due to a reduction in vapour permeability (Gavin *et al.,* 2001). Another potential mechanism relates to the negative effects of dehydration as the recorded S_{Loss} within the base layer trial (>2% BM) has been shown to reduce the potential for evaporative heat loss (Sawka & Pandolf, 1990; Gonzalez-Alonso *et al.,* 1997; Galloway, 1999). Both of these factors provide possible explanations as to why the thermoregulatory advantage was only apparent during the early stages as beyond this point evaporative heat loss was potentially restricted through a reduction in vapour permeability of the base layer and dehydration. However, these proposed mechanisms remain speculative and require further study in relation to longer exercise durations before confirmation.

Slower increases in both T_{body} and T_{sk} have been shown to significantly improve cardiovascular related variables, primarily $\dot{V}O_2$, through reducing the severity at which thermoregulation negatively effects cardiovascular function (Hunter *et al.,* 2006; Gonzalez-Alonso, 2008). Despite this evidence, the significantly lower T_{body} and T_{sk} in the base layer trial failed to translate into any significant interaction effect for $\dot{V}O_2$. However, figure 3.3 reveals that, when compared to cotton, $\dot{V}O_2$ was lower in the base layer trial throughout exercise. Subsequently, further investigation into $\dot{V}O_2$ highlights both a *P*-value close to significance for an interaction effect ($P = 0.095$) and a small effect size ($eta^2 = 0.083$). In light of these findings it becomes evident that a possible type II error may have occurred as a significant interaction may have been restricted by inadequate statistical power (Thomas *et al.,* 1991). In view of this evidence the presence of such an interaction between $\dot{V}O_2$ and garment should not be discounted for the whole population (Atkins, 2002). Consequently, it could be acknowledged that a base layers has the potentially to significantly reduce $\dot{V}O_2$ during sub maximal exercise through thermoregulatory improvements. However, as no significant interaction was detected further investigation with a larger sample size is required to support the efficacy of any claims relating to $\dot{V}O_2$.

To limit the chance of any statistical power issues arising within the main research power analysis was conducted using the number of tails and the effect size from mean T_c measurements. Calculations derived that ~12 participants would be required to produce the required statistical power within the main investigation. Consequently, this further justifies that a significant interaction for $\dot{V}O_2$ may have been apparent had a larger sample size been used as only eight participants completed the pilot study.

3.5: Summary

The pilot study revealed that, when compared to cotton, a base layer worked more effectively at reducing elevations in both T_{body} and T_{sk}. However, improvements in T_{body} were only apparent until the 20 minute data collection point, beyond which detrimental effects to evaporative heat loss caused T_{body} to increase at a superior rate to that experienced within the cotton trial. Additionally, a sample size of eight proved insufficient to produce adequate statistical power to detect significant differences in the sensitive physiological variables being measured. Consequently, these conclusions make it imperative to investigate longer exercise durations in varied environmental conditions with a sample size adequate to limit any issues in relation statistical power. Overall, the pilot study served its purpose by highlighting various potential areas for further study whilst identifying possible methodological issue that can now be rectified prior to the main research.

CHAPTER IV

METHOD

4.1: Participants

Twelve healthy males (mean ± SD; age 21 ± 1 yr, stature 1.78 ± 0.60m, BM 73.8 ± 9.8kg; $\dot{V}O_{2max}$ 54.6 ± 9.3ml·kg^{-1}·min^{-1}) who were in no way acclimatised to the heat volunteered for the investigation. Participants were informed of both the aims and potential risks before completing written informed consent (Appendix I) and a health questionnaire (Appendix II), upon which all were deemed eligible. All protocols employed had been previously approved by The University of Gloucestershire Research Ethics Committee.

4.2: Research Design

Participants completed a preliminary test to determine $\dot{V}O_{2max}$ followed by two experimental trials within each environmental condition (ambient, hot-dry and hot-humid). All possible protocol completion orders were identified and specific completion orders were assigned to ensure a counter balanced repeated measures design. Protocols were separated by 2-7 days to eliminate fatigue (Burnley *et al.,* 2001) and completed at the same time of day within an environmental chamber (Sanyo Gallenkamp PLC, Loughborough, UK) to control circadian variation (Reilly and Brooks, 1986; Waterhouse *et al.,* 1999). Euhydration was achieved by ingesting 500ml of water two hours before each protocol (ACSM, 1996; Hasegawa *et al.,* 2005) whilst participants consumed water ad-libitum until the start of each protocol. Participants abstained from alcohol, caffeine and strenuous activity for 24 hours before each protocol and were instructed to wear the same shorts, socks and footwear whilst refraining from using antiperspirants on the day of each trial. Fluid intake was prohibited, as was verbal encouragement and no indication of time was given to standardise any psychological effects (Andreacci *et al.*, 2002). Participants were familiarised with each protocol, the breathing apparatus and any data collection procedures before each protocol. Prior to the investigation five Douglas bags were evacuated and labelled, ensuring the same Douglas bags were used for specific collections. Individual seat and handle bar positions were recorded and adapted for each participant whereby an appropriate cycling position (i.e. holding the handle bars) was maintained to eliminate variations in cycling efficiency. Participants were allowed to terminate the test at any time and any protocol was terminated if a critical T_c was attained (>39 °C). Data collection was completed according to the procedures outlined below which included 8 independent variables (T_c, T_{sk}, $\dot{V}O_2$, HR RPE, thermal comfort, sweating sensations and S_{Loss}) and 2 dependant variables (environment and time).

4.3: Calibration Procedures

The dry gas meter was calibrated prior to the investigation using a 3L calibration syringe (Multiflow 3Ltr; Pulmonary Data Services Instrumentation, Laguna Niguel, CA). Atmospheric air was pumped into a Douglas bag in increments of 3L whereby the Douglas bag was then evacuated after each 3L increment was achieved i.e. 3, 6, 9, 12L etc. This continued until the 150L increment was reached whereby actual volume was plotted against recorded volume for each increment. Linear regression was used and the datum was forced through the origin (0L) whilst analysis of the slope and the resulting linear equation (3) was used to correct gas volumes accordingly:

$$V_E = (V_{rec} * 1.0187) + 0.5L \quad (3)$$

V_E represents the corrected gas volume whereby V_{rec} is the recorded volume from the dry gas meter and 1.0187 represents the slope of the graph. 0.5L represents the sample volume used within the analysis.

Following the completion of each protocol the gas analyser (1440 series paramagnetic, Servomex Ltd., Crowborough, U.K) was calibrated. Nitrogen was pumped through to establish a zero reading followed by the analysis of atmospheric air where a rotational dial was used to calibrate the analyser to the required gas content (O_2 = 20.94, CO_2 = 0.04%). A gas of known concentration (O_2 = 16.11, CO_2 = 4.06%) was then analysed to confirm calibration. If calibration was unsuccessful the procedure was repeated.

The data logging system (Spike2, Version 3.11, Cambridge Electronic Design Ltd, Cambridge, UK) used to monitor T_{sk} and T_c was calibrated prior to the investigation. Four thermistors and a digital thermometer were immersed in a hot water bath (60°C) whereby the Spike system was set into logging mode and values monitored throughout. The water bath was then cooled to 15 °C whereby as the temperature decreased values from both systems were recorded and checked for correlation. A variable resistor attached within each thermistor circuit adjusted the resistance until the values from the digital thermometer and the Spike system matched. The Spike system was then used to verify the temperature within the environmental chamber for ten minutes before each protocol.

4.4: Preliminary Test to Determine Maximal Aerobic Power

Participants completed a self-paced three minute unloaded cycling warm up followed by a ramped $\dot{V}O_{2max}$ test (Mean ± SD; Peak Power Output = 297 ± 19W; $\dot{V}O_{2max}$ = 54.6 ± 9.2ml·kg^{-1}·min^{-1}). Each test was completed on an electronically-braked cycle ergometer (Lode BV, Groningen, Netherlands) within an environmental chamber maintained at 20 °C and 35% RH. Participants cycled (60W) for 60-s following a progressive resistance increase (25W·min^{-1}) until volitional fatigue, defined as the inability to maintain >50 rev·min^{-1}, was reached. Four minutes into the protocol 30-s samples of expired air were collected every minute into a 150L Douglas bag (Cranlea and Company, Birmingham, UK) connected by a 1.22m hose (Hans Rudolph 4Ft, Cranlea and Company, Birmingham) to a three way Salford breathing valve and a subsequent mouth piece and nose clip (Cranlea and Company, Birmingham, UK) inserted throughout the protocol. Expired air was analysed post protocol within ambient conditions by flowing 60-s samples ($0.5 L \cdot min^{-1}$) through the gas analyser. Douglas bags were then evacuated using the dry gas meter whereby barometric pressure, gas temperature, CO_2 and O_2 content and corrected gas volumes were recorded to calculate $\dot{V}O_2$. For each 60-s stage $\dot{V}O_2$ was plotted against mean power whereby linear regression determined the resistance required to elicit the experimental intensity (60% $\dot{V}O_{2max}$). In the absence of a $\dot{V}O_2$ plateau, $\dot{V}O_{2max}$ was recorded as the highest $\dot{V}O_2$ observed at any time point.

4.5: Experimental Trials

Participants completed two (experimental vs. control) 60 minute continuous sub maximal cycling (60% $\dot{V}O_{2max}$) (Lode BV, Groningen, Netherlands) protocols in each environment, ambient (20 °C, 35% RH), hot-dry (30 °C, 35% RH) and hot-humid (30 °C, 80% RH). Protocols were completed in the prescribed order wearing cotton shorts, socks and running trainers alongside either a 100% cotton or a base layer t-shirt (Adidas, 2009). To standardise any insulation effect each garment was chosen according to the manufactures sizing charts and subsequently measured to insure similar skin contact and thickness.

Participants towel dried before a nude body mass assessment, accurate to ±100g, (Seca 700 Beam column scale: seca gmbh and co Ltd, Hamburg, Germany) both before (BM_{pre}) and after (BM_{post}) each trial to enable the calculation of S_{Loss} via equation (4):

$$S_{Loss} = BM_{pre} - BM_{post} \qquad (4)$$

Participants were informed about the thermal comfort, sweating sensations and RPE scales (Appendix III) following the attachment of a heart rate monitor (Vantage Polar, Kempele, Finland). Silver-silver chloride skin thermistors (ARBO Monitoring Electrodes, Welwyn Garden City, U.K) were attached to the bicep (T_{bicep}), torso (T_{torso}), quadriceps (T_{quad}) and calf (T_{calf}) area following the insertion of a rectal probe 7cm beyond the external anal sphincter. Participants then began a 3-min unloaded self paced cycling warm-up before increasing the resistance in a single step to the experimental intensity whereby a cadence of ~65rev·min^{-1} was maintained.

Core temperature and T_{sk} was logged continuously (Spike2, Version 3.11, Cambridge Electronic Design Ltd, Cambridge, UK), sampled every 1.25-s and exported to Microsoft Excel®. Temperature was determined through changes in resistance as each thermistor displayed a change in resistance that follows an exponential curve. The data logger then recorded changes in resistance whereby temperature, accurate to 0.01°C, was calculated by the Spike computer script program via equation 5:

$$\text{Temperature (°C)} = 3919.29 / ((6.75/VO - 2.25)/2.2) + 3919.29 / (298)) - 273 \qquad (5)$$

Where: VO denotes voltage output which is proportional to the resistance ratio of each thermistor.

Sixty second averages for T_{sk} and T_c were calculated and recorded at 15, 30, 45 and 60 minutes. Data from individual T_{sk} assessment sites was used to calculate mean T_{sk} via equation 6:

$$\text{Mean } T_{sk} = (0.635*T_{torso}) + (0.635*T_{quad}) + (0.35*T_{bicep}) + (0.35*T_{calf}) \quad (6)$$

(Burton, 1935)

60-s samples of expired air were collected at 15, 30, 45 and 60 minutes and analysed by the previously outlined procedures whereby the mouth piece was only worn during collection and the 30s leading up to this point. Heart rate was monitored throughout and recorded at 15, 30, 45 and 60 minutes alongside subjective ratings for RPE (Borg, 1985), thermal comfort and sweating sensations (Appendix III). All equipment had been previously assessed in relation to reliability of measures whereby all values were within the guidelines set out by the British Association of Sport and Exercise Sciences (BASES).

4.6: Data Analysis

Statistical analysis was performed in SPSS for Windows (SPSS Inc, Version 14, Chicago, Ill). Before analysis all variables were transformed into delta values (Δ) via equation 8:

$$\Delta = \text{Cotton - Base Layer} \quad (7)$$

A one-way ANOVA was performed on ΔS_{Loss} from each environment whilst a two-way repeated measures ANOVA (3 x 5; environment x time) was performed on ΔT_c, ΔT_{sk}, ΔHR, $\Delta\dot{V}O_2$, Δthermal comfort and Δsweating sensations (3 x 4; environment x time) to investigate any interaction effect. Where significant interactions were detected, a separate one-way ANOVA and Bonferroni corrected paired t-tests were implemented to further investigate any main effects. In all cases the significance level was set at $P < 0.05$. All empirical data is expressed as mean ± SD unless otherwise stated.

CHAPTER V

RESULTS

5.1: Core Temperature

Repeated measures ANOVA showed no significant interaction effect (environment x time; P = 0.543, eta^2 = 0.171), main effect for environment (P = 0.314) or main effect for time (P = 0.057) on ΔT_c. Core temperature and ΔT_c values can be seen in table 5.1 and figure 5.1 respectively.

Table 5.1: Core temperature (°C) response throughout experimental trials.

	Ambient		Hot-Dry		Hot-Humid	
Time (min)	Base Layer	Cotton	Base Layer	Cotton	Base Layer	Cotton
0	37.0 ± 0.2	37.0 ± 0.3	37.1 ± 0.2	37.2 ± 0.3	37.0 ± 0.4	37.1 ± 0.3
15	37.4 ± 0.3	37.4 ± 0.5	37.5 ± 0.3	37.8 ± 0.3	37.5 ± 0.3	37.6 ± 0.4
30	37.8 ± 0.4	37.8 ± 0.5	38.0 ± 0.2	38.3 ± 0.4	38.0 ± 0.3	38.1 ± 0.3
45	37.9 ± 0.5	38.0 ± 0.4	38.5 ± 0.3	38.8 ± 0.3	38.2 ± 0.6	38.4 ± 0.3
60	37.8 ± 0.6	38.3 ± 0.3	38.6 ± 0.4	38.9 ± 0.4	38.3 ± 0.5	38.7 ± 0.5

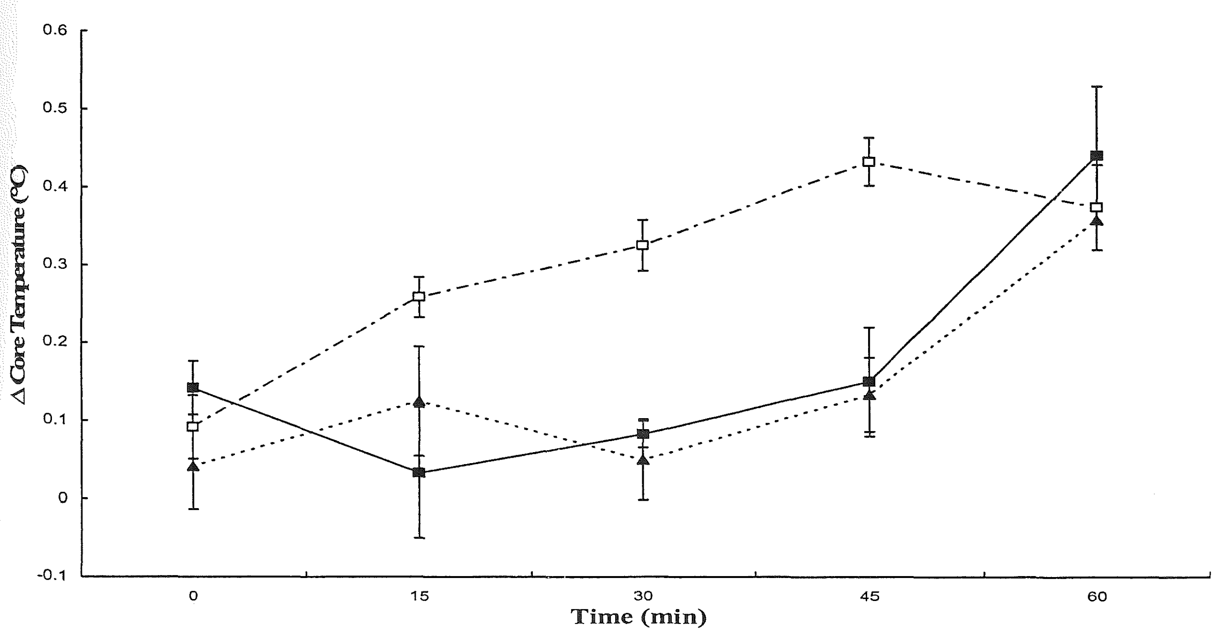

Figure 5.1: Change in Δcore temperature throughout experimental trials. Values expressed as mean Δ ± SE. (■) = ambient; (□) = hot-dry; (▲) = hot-humid.

5.2: Mean Skin Temperature

Repeated measures ANOVA revealed no significant interaction effect (environment x time; P = 0.511, $eta^2 = 0.197$), main effect for environment (P = 0.123) or main effect for time (P = 0.314) on ΔT_{sk}. Skin temperature and ΔT_{sk} values can be seen in table 5.2 and figure 5.2 respectively.

Table 5.2: Mean skin temperature (°C) response throughout experimental trials.

	Ambient		Hot-Dry		Hot-Humid	
Time (min)	Base Layer	Cotton	Base Layer	Cotton	Base Layer	Cotton
0	30.7 ± 1.0	31.3 ± 1.0	33.1 ± 0.7	33.8 ± 1.1	33.4 ± 0.9	34.0 ± 0.9
15	31.7 ± 1.0	32.3 ± 0.7	33.9 ± 0.9	35.0 ± 1.0	34.3 ± 0.8	34.9 ± 0.7
30	31.6 ± 1.0	32.2 ± 0.7	34.0 ± 0.9	35.2 ± 1.0	34.6 ± 0.6	35.0 ± 0.4
45	31.4 ± 0.8	31.8 ± 1.0	33.8 ± 1.3	35.1 ± 1.2	34.7 ± 0.6	35.1 ± 0.4
60	31.4 ± 0.7	31.7 ± 0.9	33.8 ± 1.6	35.0 ± 1.4	34.6 ± 1.0	35.2 ± 0.9

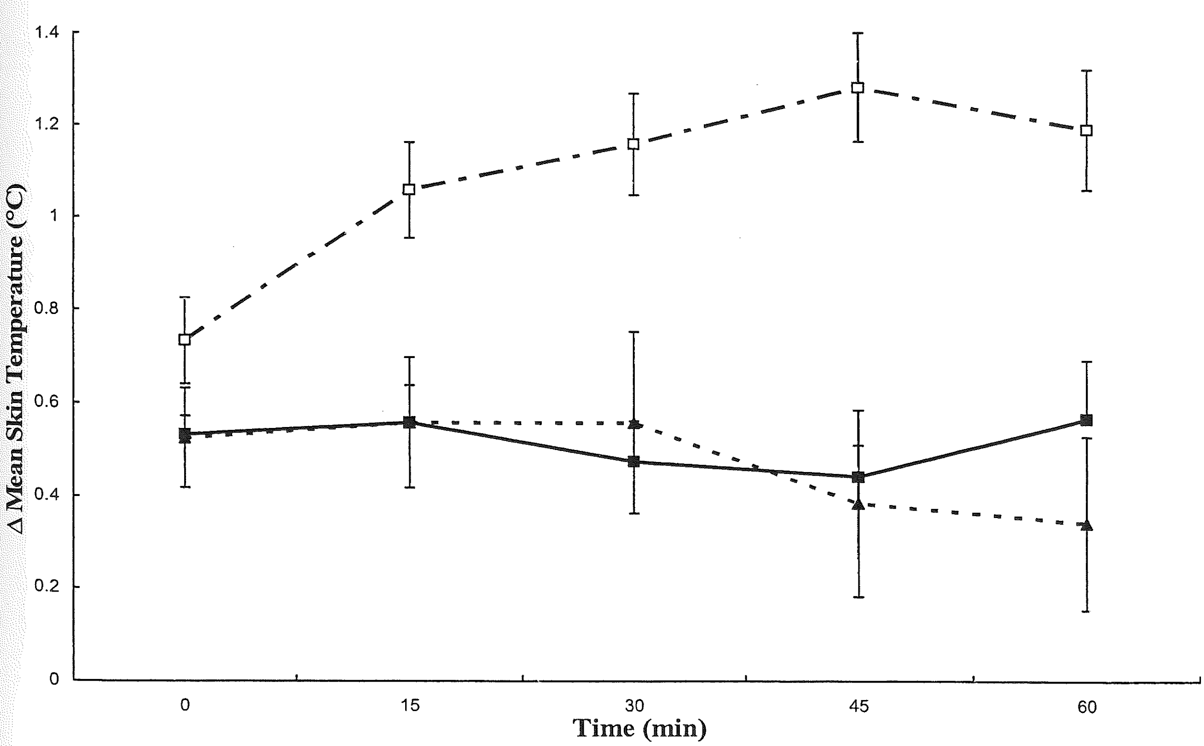

Figure 5.2: Change in Δmean skin temperature throughout experimental trials. Values expressed as mean Δ ± SE. (■) = ambient; (□) = hot-dry; (▲) = hot-humid.

5.3: Oxygen Uptake

Repeated measures ANOVA revealed a significant interaction effect (environment x time; P = 0.038, eta^2 = 0.479), a main effect for time (P = 0.02) whilst no main effect for environment (P = 0.089) was detected on $\Delta \dot{V}O_2$. A one-way ANOVA on each environment showed a significant main effect for time within the hot-dry condition only (P = 0.003) as no effect within the ambient (P = 0.426) or hot-humid environment (P = 0.183) was evident. Pairwise comparisons and Bonferroni corrected t-tests showed significant differences between 15 to 45 (P = 0.048), 15 to 60 (P = 0.017), and 45 to 60 minutes (P = 0.049) within the hot-dry environment. Oxygen uptake and $\Delta \dot{V}O_2$ values can be seen in table 5.3 and figure 5.3 respectively.

Table 5.3: Oxygen uptake (L·min^{-1}) response to experimental trials.

	Ambient		Hot-Dry		Hot-Humid	
Time (min)	Base Layer	Cotton	Base Layer	Cotton	Base Layer	Cotton
15	2.34 ± 0.48	2.44 ± 0.46	2.46 ± 0.50	2.62 ± 0.46	2.48 ± 0.39	2.44 ± 0.38
30	2.45 ± 0.48	2.60 ± 0.45	2.46 ± 0.49	2.75 ± 0.51	2.42 ± 0.36	2.59 ± 0.35
45	2.56 ± 0.48	2.59 ± 0.41	2.44 ± 0.48	2.72 ± 0.50	2.46 ± 0.36	2.59 ± 0.34
60	2.63 ± 0.47	2.78 ± 0.48	2.59 ± 0.63	2.94 ± 0.60	2.48 ± 0.42	2.83 ± 0.47

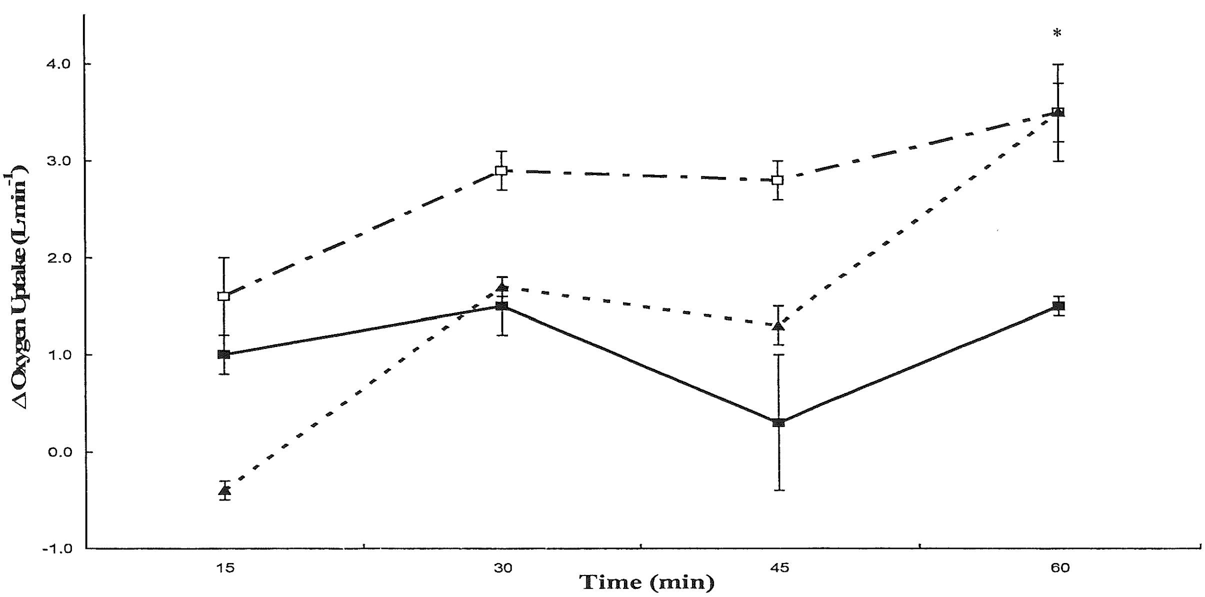

Figure 5.3: Change in Δoxygen uptake during experimental trials. Values expressed as mean Δ ± SE. (■) = ambient; (□) = hot-dry; (▲) = hot-humid. * denotes significantly higher in the hot-dry environment

5.4: Heart Rate

Repeated measures ANOVA showed no significant interaction effect (environment x time; P = 0.217, $eta^2 = 0.218$) or main effect for environment (P = 0.64) whilst a significant main effect for time (P = 0.007) on ΔHR was detected. Pairwise comparison and Bonferroni corrected t-tests revealed significant differences between 15 and 30 (P = 0.002), 15 and 60 (P = 0.037) and 30 and 45 minutes only (P = 0.013). Heart rate and ΔHR values can be seen in table 5.4 and figure 5.4 respectively.

Table 5.4: Heart rate ($b \cdot min^{-1}$) response during experimental trials

	Ambient		Hot-Dry		Hot-Humid	
Time (min)	Base Layer	Cotton	Base Layer	Cotton	Base Layer	Cotton
15	154 ± 14	157 ± 11	158 ± 14	162 ± 14	159 ± 12	159 ± 7
30	161 ± 16	163 ± 12	167 ± 10	171 ± 10	164 ± 14	167 ± 10
45	162 ± 15	167 ± 12	168 ± 10	175 ± 8	167 ± 12	174 ± 9
60	165 ± 14	172 ± 13	173 ± 8	180 ± 7	172 ± 9	176 ± 8

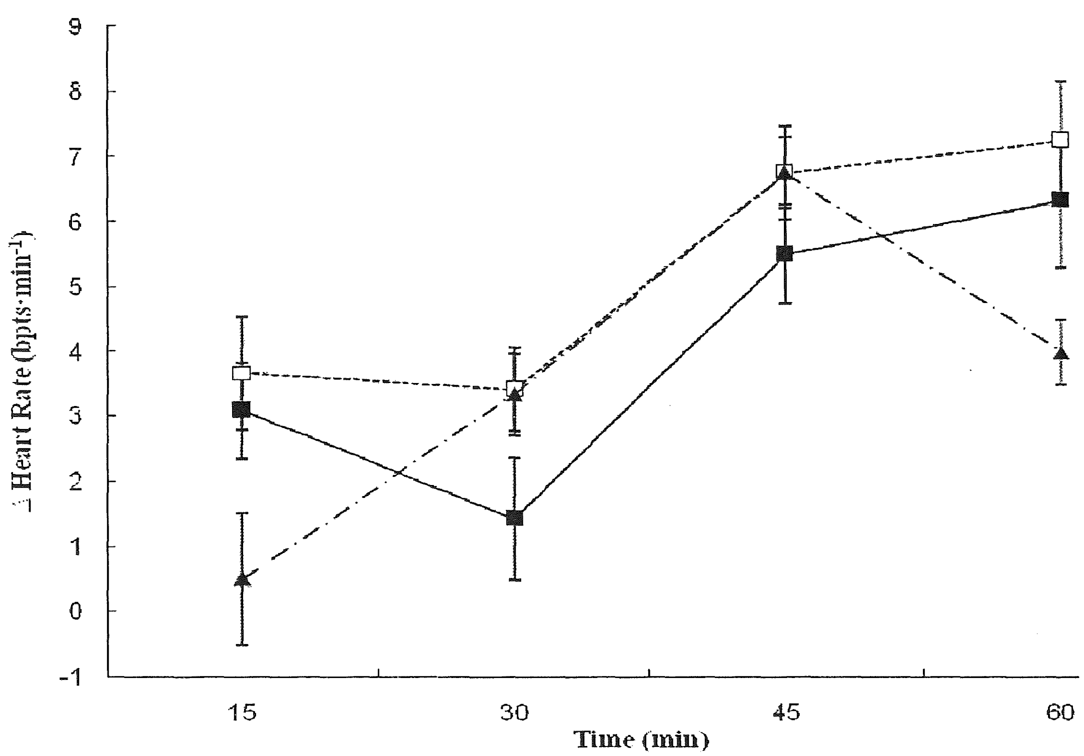

Figure 5.4: Change in ΔHR during experimental trials. Values expressed as mean Δ ± SE. (■) = ambient; (□) = hot-dry; (▲) = hot-humid.

5.5: Rating of Perceived Exertion

Repeated measures ANOVA showed no significant interaction effect (environment x time; P = 0.219, $eta^2 = 0.329$) or main effect for time (P = 0.548) whilst a significant main effect for environment (P < 0.001) was detected on ΔRPE. Pairwise comparisons and Bonferroni corrected T-tests revealed a significant difference between ambient and hot-humid (P = 0.020) and hot-dry and hot-humid environments (P = 0.002) whilst no significant difference was detected between ambient and hot-dry (P = 0.304). Ratings of perceived exertion and ΔRPE can be seen in table 5.5 and figure 5.5 respectively.

Table 5.5: Rating of perceived exertion during experimental trials.

	Ambient		Hot-Dry		Hot-Humid	
Time (min)	Base Layer	Cotton	Base Layer	Cotton	Base Layer	Cotton
15	11.5 ± 1.2	12.7 ± 1.2	12.3 ± 1.0	13.3 ± 1.2	12.7 ± 1.0	12.7 ± 1.2
30	13.5 ± 1.6	14.1 ± 1.0	14.1 ± 1.2	15.6 ± 1.6	14.8 ± 1.2	14.3 ± 1.0
45	14.8 ± 1.2	15.5 ± 1.4	15.3 ± 1.1	17.0 ± 1.9	16.5 ± 1.1	16.3 ± 1.5
60	15.8 ± 1.7	16.3 ± 1.2	16.8 ± 1.1	18.6 ± 1.9	18.2 ± 1.5	18.4 ± 1.6

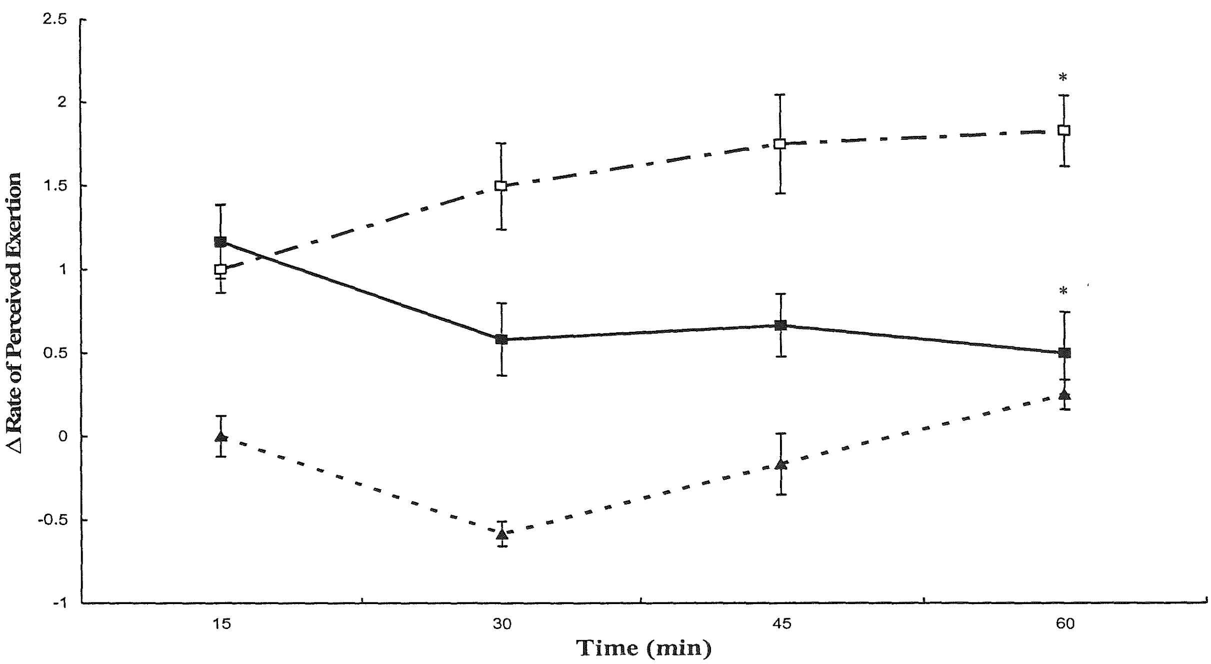

Figure 5.5: Change in ΔRPE throughout experimental trials. Values expressed as mean Δ ± SE. (■) = ambient; (□) = hot-dry; (▲) = hot-humid. * denotes significantly higher than hot-humid environment.

5.6: Thermal Comfort

Repeated measures ANOVA showed no significant interaction effect (environment x time; P = 0.129, eta^2 = 0.412) or a main effect for time (P = 0.825) whilst a significant main effect for environment (P = 0.026) was detected for Δthermal comfort. Pairwise comparisons and Bonferroni corrected t-tests revealed a significant difference between the ambient and hot-humid environment only (P = 0.023) as no other significant differences between environments were evident. Thermal comfort and Δthermal comfort values can be seen in table 5.6 and figure 5.6 respectively.

Table 5.6: Thermal comfort response during experimental trials.

	Ambient		Hot-Dry		Hot-Humid	
Time (min)	Base Layer	Cotton	Base Layer	Cotton	Base Layer	Cotton
15	1.6 ± 1.1	2.3 ± 0.9	2.9 ± 0.7	3.2 ± 0.7	2.8 ± 0.4	2.8 ± 0.6
30	2.5 ± 0.8	2.7 ± 0.9	3.3 ± 1.0	3.7 ± 1.0	3.3 ± 0.5	3.6 ± 0.7
45	2.8 ± 0.8	3.3 ± 1.0	3.8 ± 0.7	4.1 ± 0.8	4.2 ± 0.7	4.0 ± 0.7
60	3.1 ± 0.8	3.3 ± 1.1	4.1 ± 0.5	4.6 ± 0.5	4.3 ± 0.7	4.4 ± 0.8

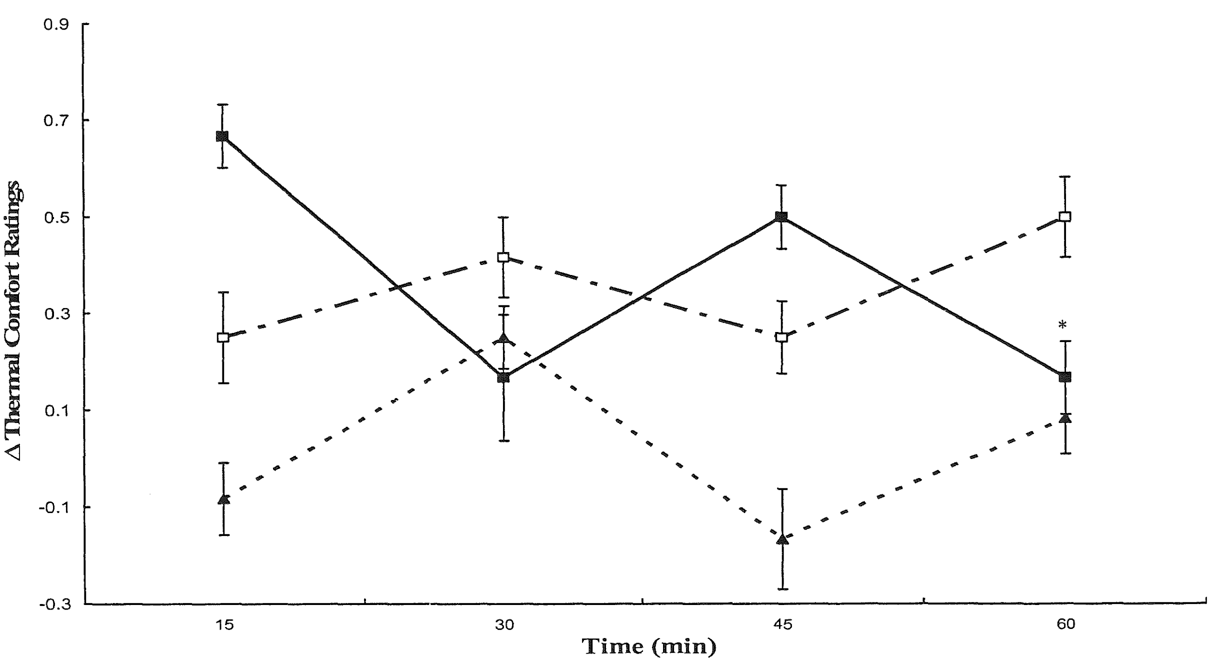

Figure 5.6: Change in Δthermal comfort ratings throughout experimental trials. Values expressed as mean Δ ± SE. (■) = ambient; (□) = hot-dry; (▲) = hot-humid. * denotes significantly higher than hot-humid environment.

5.7: Sweating Sensations

Repeated measures ANOVA showed no significant interaction effect (environments x time; P = 0.141, eta^2 = 0.352) or main effect for time (P = 0.442) whilst a significant main effect for environments (P = 0.044) was detected on Δsweating sensation. Pairwise comparisons and Bonferroni corrected t-test revealed a significant difference between the hot-dry and hot-humid environments (P = 0.038) only as no other significant differences between environments were detected. Sweating sensation and Δsweating sensation values can be seen in table 5.7 and figure 5.7 respectively.

Table 5.7: Sweating sensation response throughout experimental trials.

	Ambient		Hot-Dry		Hot-Humid	
Time (min)	Base Layer	Cotton	Base Layer	Cotton	Base Layer	Cotton
15	2.1 ± 0.7	2.3 ± 0.9	3.9 ± 1.0	4.4 ± 0.8	3.7 ± 0. 5	3.0 ± 0.7
30	3.2 ± 0.9	3.2 ± 1.0	4.5 ± 0.5	4.8 ± 0.5	4.4 ± 0.5	4.2 ± 0.8
45	4.0 ± 1.0	3.8 ± 1.0	4.8 ± 0.4	4.9 ± 0.3	4.7 ± 0.5	4.3 ± 0.8
60	4.3 ± 0.6	4.1 ± 0.9	5.0 ± 0.0	4.9 ± 0.3	4.6 ± 0.5	4.4 ± 0.9

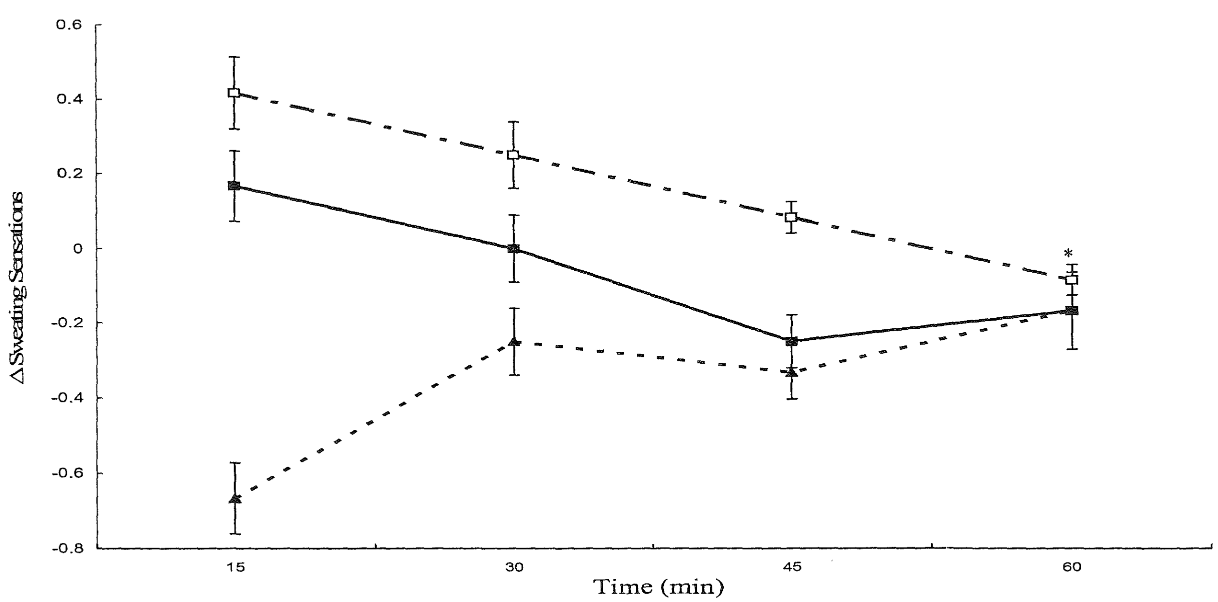

Figure 5.7: Change in Δsweating sensations throughout experimental trials. Values expressed as mean Δ ± SE. (■) = ambient; (□) = hot-dry; (▲) = hot-humid. * denotes significantly higher in the hot-dry than the hot-humid environment.

5.8: Estimated Sweat Loss

A one-way ANOVA revealed a significant effect on ΔS_{Loss} between environments (ambient, hot-dry, hot-humid; $P < 0.001$). Bonferroni corrected t-tests revealed a significant difference in ΔS_{Loss} between garments within the hot-dry environment only ($P < 0.001$) as no significant differences between garments were evident in either the ambient ($P = 0.815$) and hot-humid environment ($P = 0.983$). Sweat loss and ΔS_{Loss} values can be seen in table 5.8 and figure 5.8 respectively.

Table 5.8: Estimated sweat loss (kg) within each environment

	Ambient	Hot-Dry	Hot-Humid
Base Layer	1.87 ± 0.23	1.95 ± 0.20	1.86 ± 0.20
Cotton	1.83 ± 0.23	0.94 ± 0.23	1.83 ± 0.23

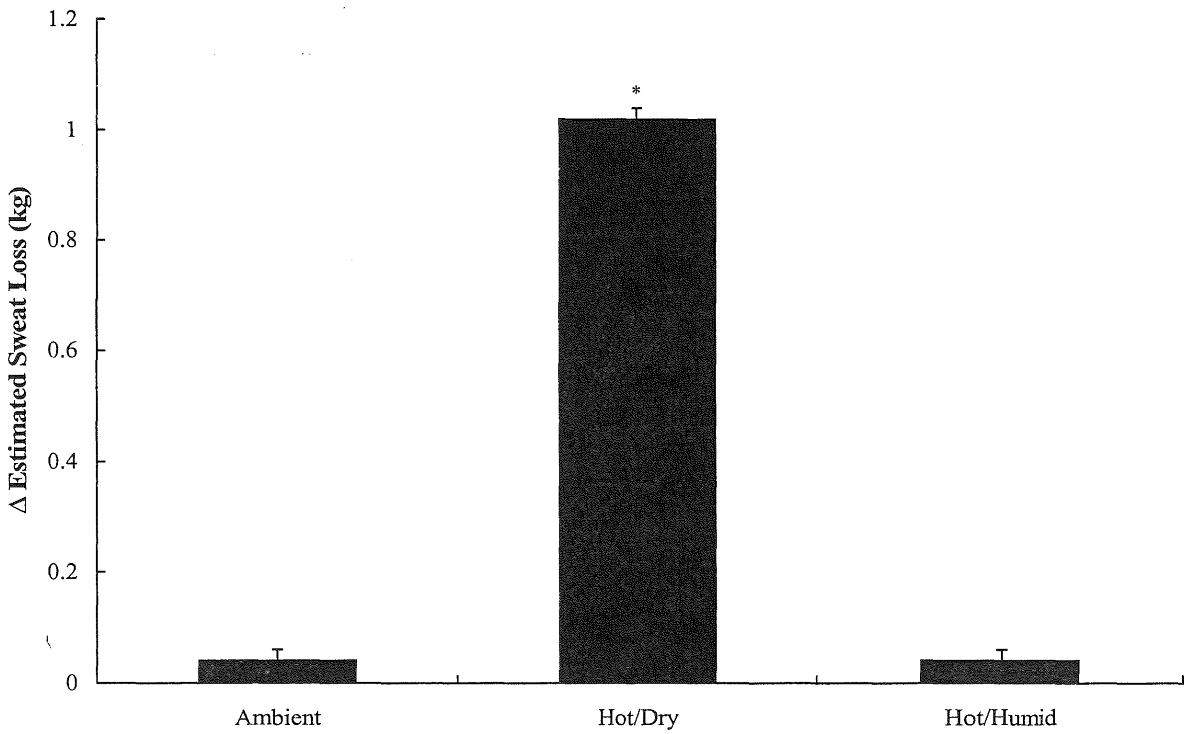

Figure 5.8: Estimated sweat loss within each environment. Values expressed as mean Δ ± SD (kg). * denotes significantly higher in the hot/dry condition.

CHAPTER VI
DISCUSSION

6.1 Key Findings

Physiological responses to sub maximal exercise were significantly improved when a base layer was worn during exercise within hot-dry environmental conditions. A significant interaction effect (environment x time) for $\Delta\dot{V}O_2$ was detected whereby further post-hoc analysis on each environment revealed a significant increase in $\Delta\dot{V}O_2$ after 45 minutes within the hot-dry environment only. This indicates the base layer significantly improved exercise economy by reducing the oxygen required to work at a fixed intensity after 45 minutes of exercise within the hot-dry environment. A significant increase in ΔS_{Loss} within the hot-dry environment was evident indicating that when compared to cotton, the base layer significantly increased S_{Loss} within the hot-dry environment. A main effect for time was detected on ΔHR, revealing that over time base layers had a greater effect than cotton at reducing increases in HR. A significant effect for environment on Δsweating sensations was detected within the hot-dry when compared to the hot-humid environment. This indicated that the base layer worked more effectively at improving feelings of wetness within the hot-dry when compared to the hot-humid environment. A significant effect for environment on ΔRPE was detected within both ambient and hot-dry environments (vs. hot-humid), revealing that base layers worked more effectively than cotton at reducing increases in RPE when RH was lower. No significant differences were detected within either ambient or hot-humid environments which indicates that when compared to cotton, base layers had no effect at altering physiological or thermoregulatory responses to exercise within either of these environments. In contrast to previous research (Gavin *et al.,* 2001; Roberts *et al.,* 2007) base layers provided a physiological advantage during sub maximal exercise in hot-dry environmental conditions.

6.2: Explanation of Results

The investigation aimed to interrogate the difference between two garments within three environmental conditions. This research design created three independent variables (environment, time and garment), requiring a three-way ANOVA that produces results in three dimensions (x, y and z axis). Three-way analysis complicates both the investigation of significant differences and the interpretation of results for the reader. To simplify statistical analysis Δ values were calculated (cotton - base layer) to eliminate an independent variable and make a two-way ANOVA possible. Two way ANOVA of Δ values failed to alter any statistical outcomes as when compared to a three-way ANOVA based on raw data, the same P-values are obtained. Delta values simultaneously satisfied the aims of the investigation whilst simplifying both the analysis and interpretation of results for the reader. Therefore, any significant differences discussed below relate to positive Δ values that indicate when compared to cotton, base layers significantly improved that particular variable.

A significant interaction effect (environment x time) on $\Delta \dot{V}O_2$ was detected whereby further one way analysis on each environment and Bonferroni corrected T-tests revealed a significant increase in $\Delta \dot{V}O_2$ after 45 minutes within the hot-dry environment only. This indicates that when compared to cotton, base layers significantly improved exercise economy within the hot-dry environment after 45 minutes of exercise. Improvements to exercise economy indicate that base layers decreased the oxygen required to work at a fixed intensity, indicating that higher intensities are sustainable for similar $\dot{V}O_2$ responses whereby athletes can increase exercise duration and/or intensity before the development of fatigue (Gaesser and Poole, 1996). Improvements to exercise economy are highly correlated with better endurance performance times (Conley and Krahenbuhl, 1980; Plank *et al.,* 2005) which suggests this may translate into a potential performance advantage. However, as no performance measures were evaluated this suggestion remains speculative and requires further study.

During steady state exercise in hot environmental conditions $\dot{V}O_2$ is modulated by various factors influenced by T_c and HR (Kaufman, 1995; Piepoli *et al.,* 1995; Gonzalez-Alonso *et al.,* 1999; Hayashi, 2006) whereby the significant improvement in exercise economy could potentially relate to the main effect for time on ΔHR. However, further interrogation of ΔT_c within the hot-dry environment highlights that a combination of both HR and T_c response are required to potentially explain the proposed mechanisms for this improvement.

Despite significant elevations in S_{Loss} within the hot-dry environment, the base layer failed to significantly reduce T_c which indicates that when compared to cotton, the base layers inhibited thermoregulation within the hot-dry environment. However, the likelihood of detecting a significant difference on ΔT_c within the hot-dry environment was restricted by inadequate effect size ($eta^2 < 0.2$). This low effect size was potentially caused by the small range of ΔT_c (Moran and Mendall, 2002) whilst the absence of any significant differences within either the ambient or hot-humid environment further decreased effect size through increases in variance (Thomas *et al.,* 1991). In view of this low statistical power and the *P*-value close to significance for an interaction effect ($P = 0.057$) the presence of such an interaction between ΔT_c and garment should not be discounted for the whole population (Atkins, 2002). Consequently, the best way to conceptualise the interaction between ΔT_c and garment within the hot-dry environment is to evaluate differences in the gradient of ΔT_c (Atkins, 2002). Therefore, one-way analysis was conducted on ΔT_c from the hot-dry environment whereby a significant linear trend for time was detected ($P = 0.03$). This indicates that over time base layers worked more efficiently than cotton at reducing elevations in T_c within the hot-dry environment. This improvement potentially decreases the extent to which thermoregulatory responses negatively affect cardiovascular function. These improvements could provide an explanation to the main effect for time on ΔHR as any detrimental variations in stroke volume, cardiac output, muscle blood flow and myocardial oxygen consumption that increase HR will decline as a result of the lower rate at which T_c increased.

The significant main effect for time on ΔHR ($P = 0.007$) indicates that over time, base layers worked more effectively than cotton at reducing elevations in HR whereby this conflicts with both Gavin *et al.,* 2001 and Roberts *et al.,* 2007. This main effect is potentially a product of the linear trend for time on ΔT_c as the lower heat storage rate created by the base layer reduces peripheral blood flow demand, thereby allowing muscle blood flow to be maintained (Gonzalez-Alonso, 2007). Additionally, reductions T_c means that the HR necessary to maintain cardiac output and stroke volume decreases as these are easier to maintain under conditions of less thermal stress (Gonzalez-Alonso, 2007; Wendt *et al.,* 2007). Consequently, the athlete's ability to maintain competing blood flow demands increases without compromising cardiovascular or thermoregulatory dynamics (Gonzalez-Alonso *et al,* 2001). These potential improvements to cardiovascular function reduce variations in substrate supply, hormone release (Gonzalez-Alonso, 2007) and lactate production (Febbraio *et al.,* 1994; Gonzalez-Alonso *et al.,* 1999) whilst improving the removal of metabolites (Gray and Nimmo, 2001; Kay *et al.,* 2001). The combination of these physiological variations alongside the improved ability to maintain both competing blood flow demands and cardiac output potentially explain how the base layer, when compared to cotton, significantly improved exercise economy within the hot-dry environment. However, the data suggests these proposed improvements to cardiovascular function only occur when either exercise duration or thermal stress allow the base layer to significantly reduce increases in T_c to the extent whereby the combination of a decline in peripheral blood flow demand and the improved maintenance of cardiac output reduces elevations in HR. This offers an explanation as to why the significant increase in exercise economy was only evident after 45 minutes as prior to this point it suggests either exercise duration or thermal stress were insufficient to allow the base layer to affect T_c and HR. However, despite the present investigation reporting that base layers significantly improved exercise economy within the hot-dry environment the proposed mechanisms for such an improvement remain speculative and require further study before confirmation.

No significant differences were detected within either ambient or hot-humid environments, indicating that when compared to cotton, base layers failed to alter physiological or thermoregulatory responses to exercise within either of these environments. A potential explanation for this relates to the thermal stress of exercise and the evaporative capacity of the environment within the ambient and hot-humid environments respectively. The exclusion of external heat within the ambient environment eliminated the possibility of either ΔT_c or ΔHR reaching sufficient levels as inadequate thermal stress caused maximum mean T_c (37.8 °C) to remain within optimal limits. Failure to elevate T_c beyond optimal limits not only reduces the range of ΔT_c but minimises any potential advantage gained through the base layer's superior wicking and regain properties as sweat rate is minimal when the body is in homeostasis. Alternatively, despite inducing adequate thermal stress within the hot-humid environment, the decreased evaporative capacity of the environment potentially negated the superior wicking and regain capabilities of the base layer to the extent whereby only a minimal increase in ΔT_c was attainable (Gavin *et al.,* 2001). These explanations also provide a potential reason why the investigation reports data conflicting with that produced by both Gavin *et al.,* 2001 and Roberts *et al.,* 2007 in relation to significant changes in HR. Data presented by Gavin *et al.,* (2001) shows that inadequate thermal stress restricted elevations in T_c whereby maximum mean T_c (~38.2 °C) remained within optimal limits. As previously stated, failure to adequately stress the thermoregulatory system prior to the termination of exercise means any thermoregulatory responses during exercise would have been minimal (Gonzalez-Alonso *et al.,* 1999). This not only minimises any advantage gained by the superior characteristics of the base layer but it restricts any increase in ΔHR that potentially improves cardiovascular function as the aforementioned variations in circulation and blood volume fail to manifest. This possible suggests that had Gavin *et al.,* (2001) induced greater thermal stress during exercise the resulting increases in S_{Loss} alongside the reported significant improvements to evaporative efficiency may have significantly effected T_c, $\dot{V}O_2$, and/or HR, as seen within the current investigation.

6.3: Sweat Loss and Dehydration

Conflicting with Gavin *et al.,* (2001) the present investigation reports that when compared to cotton, base layers significantly increased S_{Loss} within hot-dry environmental conditions. Despite this contrast, Gavin *et al.,* (2001) reported that increases in S_{Loss} should have accompanied the reported improvement to evaporative efficiency, a conclusion that was later supported by Roberts *et al.,* (2007). However, Gavin *et al.,* (2001) stated that a significant difference in S_{Loss} was not detected due to the precision of the scales (±10g), claiming that the variability of data prevented a difference of ~100g being significant, a difference that was much greater than the precision of the scales. Alternatively, a difference that is 10 fold to the precision of the scales should be detectable regardless of the extent of the heterogeneity of the data (Thomas *et al.,* 1991). However, without the raw data we can only speculate that base layers may have increased S_{Loss} within Gavin *et al.,* (2001) whereby errors in the analysis and interpretation of results potentially restricted this finding.

The negative effects of dehydration are well documented (Sawka & Pandolf, 1990; Gonzalez-Alonso *et al.,* 1997; Galloway, 1999; Oppliger and Bartok, 2002) whereby they potentially become a major concern when wearing a garment that increases S_{Loss} during performance. Within the hot-dry environment base layers promoted a mean BM loss of 2.68% which is agreed by many to negatively effect both thermoregulation and performance (Sawka & Pandolf, 1990; Gonzalez-Alonso *et al.,* 1997; Galloway, 1999). These negative effects failed to be apparent within the current investigation, suggesting that the improvements to cardiovascular function that potentially increased exercise economy within the hot-dry environment still manifest when moderate dehydration is reached (<3% BM loss). However, during higher intensities (>60% $\dot{V}O_{2max}$) and/or extended exercise durations (>60 minutes) elevations in S_{Loss} could potentially increase to the extent whereby excessive dehydration manifests (>3% BM loss). Excessive dehydration combined with the elevations in T_c associated with exercise in hot environments decreases blood volume to the extent whereby the discussed decline in stroke volume, cardiac output and muscle blood flow increases (Gonzalez-Alonso *et al.,* 1999; Hargreaves, 2008). Consequently, given any further significant increase in S_{Loss} than that detected within the hot-dry base layer trial, both skin perfusion (Kenney *et al.,* 1990) and evaporative heat loss (Sawka *et al.,* 1989; Kenny *et al.,* 1990; Gonzalez-Alonso *et al.,* 1995) would potentially decline to the extent that thermoregulation is inhibited. This data highlights a potential a point at which the increases in S_{Loss} caused by the base layer may inhibit thermoregulation and restrict any potential improvements to cardiovascular function. Consequently, a physiological disadvantage may manifest when exercise duration, intensity or environmental temperature increase beyond that experienced within the present investigation. However, as the negative effects of dehydration are not evident within the present investigation these suggestions remain speculative and require further research.

6.4: Subjective Comfort Ratings

Two way ANOVA revealed a significant increase in Δthermal comfort within the ambient environment when compared to the hot-humid environment (P = 0.023). This indicates that the base layer worked more effectively than cotton at reducing any increase in thermal comfort within the ambient environment than the hot-humid environment. However, this was to be expected due to the increase in RH as both earlier suggestions and evidence from Gavin *et al.*, (2001) demonstrated that any improvements provided by the base layer are potentially minimised when RH elevates.

A significant increase in Δsweating sensations was evident within the hot-dry environment when compared to the hot-humid environment (P = 0.038). This indicates that when compared to cotton, base layers worked more effectively at reducing feelings of wetness within the hot-dry environment than the hot-humid environment. This suggests that during exercise in the heat the base layer's superior wicking and regain properties worked more efficiently at absorbing sweat away from the skin when RH was lower. The data also highlights that within the ambient environment, when metabolic heat production was the only heat source, no improvement in sweating sensations was provided by the base layer. However, this was to be expected as the failure to elevate mean T_c beyond optimal limits restricted any elevations in sweat rate. Equally as expected was the aforementioned significant increase in Δsweating sensations between hot-dry and hot-humid environments as the increased RH within the hot-humid environment would translate into the athlete feeling wetter despite no increase in skin wetness or evaporative efficiency. However, the simplicity of the sweating sensations scale fails to account for this effect whereby to better understand this relationship additional research and development of the sweating sensation scale is necessary.

In line with previous research (Gavin *et al.,* 2001; Roberts *et al.,* 2007) the present investigation reports that base layers failed to significantly alter RPE when compared cotton. However, despite no significant differences were found within any individual environment (base layer vs. cotton), when compared to the hot-humid environment mean RPE was lower in both the hot-dry and ambient conditions. This indicates that despite failing to significantly alter RPE within any single environment, when compared to the hot-humid environment, base layers worked more effectively than cotton at reducing increases in RPE within both the ambient and the hot-dry environments. A potential explanation to why base layers worked more effectively within the hot-dry environment relates to the progressive reduction in the rate of HR increase and the subsequent improvement to exercise economy evident within this environment (Ueda and Kurokawa, 1991). However, this fails to explain why base layers also worked more effectively within the ambient environment. Consequently, an explanation appears to be related to the RH of the environment as within both the hot-dry and ambient environment RH was lower. This further supports the statement made previously within both the present investigation and by Gavin *et al.,* (2001) which stated increases in RH negate the proposed improvements provided by the base layer. However, reductions in RPE may become evident if exercise duration and/or intensity increase as the base layer's ability to attenuate increases in T_c, HR and exercise economy improves as exercise progresses. Reductions in RPE have been associated with improvements in self-paced time trial performance (Atkinson and Brunskill, 2002) whilst also suggesting a decline in the effect of fatigue (Nybo and Nielsen, 2001). However, further research needs to evaluate if increases in exercise duration and/or intensity produce significant reductions in RPE as this has not been proven to date.

6.5: Recommendations for Future Research

Primarily, research is warranted to further investigate the relationship between base layers, T_c and the proposed variations in cardiovascular function. Within the present investigation inadequate effect size restricted the possibility of detecting a significant difference on ΔT_c within the hot-dry condition whereby one-way analysis was used to conceptualise this effect and a significant linear trend for time was evident. Further investigation should aim to verify reports that base layers significantly reduce T_c during exercise within hot-dry environmental conditions by improving effect size through increases in participants (n >12). Additionally, the inclusion of data relating to stroke volume and cardiac output within this research would evaluate the speculative mechanism for the increase in $\Delta \dot{V}O_2$ within the present investigation.

Base layers promoted a mean BM loss of 2.68% within the hot-dry environment whereby no negative effects of dehydration were evident. However, increases in either exercise duration or intensity will further increase S_{Loss} whereby any further dehydration (>3%BM) may decrease blood volume to the extent that the potential improvements to cardiovascular function may not manifest (Gonzalez-Alonso *et al.,* 1999). Therefore, further research needs to include increases in either exercise intensity (>60% $\dot{V}O_{2max}$) or duration (>60 minutes) to establish if there is a point when base layers negatively effect both thermoregulatory and physiological responses to exercise because of dehydration. However as exercise intensity increases time to fatigue decreases (Poole & Richardson, 1997), thereby any increases in intensity must not limit exercise duration to an extent that the thermoregulatory system is not stressed prior to fatigue.

6.6: Summary

Conflicting with previous research (Gavin *et al.,* 2001; Roberts *et al.,* 2007) the present investigation is the first to report that when compared to cotton, base layers significantly improved physiological responses to sub maximal exercise within hot-dry environmental conditions. Within this condition significant increases were detected within $\Delta \dot{V}O_2$ and ΔS_{Loss} whilst ΔHR and ΔT_c increased with exercise duration. This indicates that within the hot-dry environment base layers improved exercise economy and increased sweat rate whilst progressively reducing elevations in both HR and T_c as exercise duration increased.

Within the hot-dry environment the combination of the base layer's superior wicking and regain properties and the significant increase in ΔS_{Loss} potentially translated into a significant linear trend for time on ΔT_c. This suggested that by increasing evaporative heat loss the base layer progressively attenuated increases in T_c whereby this lower heat storage rate potentially improved the ability to maintain cardiac output, stroke volume and both muscle and peripheral blood flow demands. Consequently, the HR required to maintain cardiac output and both muscle and peripheral blood flow declines. This potentially translated into the main effect for time on ΔHR which indicates the base layer worked more effectively than cotton at reducing elevations in HR as exercise progressed. This improvement to cardiovascular function potentially induced numerous physiological improvements relating to substrate supply, hormone release, lactate production and the removal of metabolites (Gray and Nimmo, 2001; Kay *et al.,* 2001). These suggested variations in cardiovascular function potentially caused the significant increase in $\Delta \dot{V}O_2$. This indicated that when compared to cotton, base layers improved exercise economy and subsequently decreased the oxygen required to work at a fixed intensity whereby athletes can increase exercise duration and/or intensity before the development of fatigue (Gaesser and Poole, 1996). A potential performance advantage was also suggested because improvements to exercise economy have been correlated with better endurance performance times as athletes can sustain higher intensities for similar $\dot{V}O_2$ responses. However, data indicates that the proposed improvements only occur when exercise duration and/or thermal stress are sufficient to elevate T_c beyond optimal limits and allow both ΔT_c and ΔHR to elevate to sufficient levels to alter cardiovascular function between garments. No significant differences were detected within any other environment as metabolic heat production alone failed to induce sufficient thermal stress whilst the evaporative capacity of the environment negated increases in S_{Loss} within the ambient and hot-humid environments respectively. Overall, the investigation reports that base layers significantly improved exercise economy within the hot-dry environment by increasing S_{Loss} and attenuating increases in HR and T_c that potentially improved cardiovascular function. However, these proposed mechanisms remain speculative and require further study before confirmation.

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APPENDIX II

UNIVERSITY OF
GLOUCESTERSHIRE

SPORT & EXERCISE LABORATORIES

Health Questionnaire

About this questionnaire:
The purpose of this questionnaire is to gather information about your health and lifestyle. We will use this information to decide whether you are eligible to take part in the testing for which you have volunteered. It is important that you answer the questions truthfully. The information you give will be treated in confidence. Your completed form will be stored securely for 5 years and then destroyed.

Section 1, which has been completed by the tester, provides basic information about the testing for which you have volunteered. Sections 2 to 7 are for you to complete: please circle the appropriate response or write your answer in the space provided. Please also complete section 8. Sections 9 and 10 will be completed by the tester, after you have completed sections 2 to 8.

Section 1: The testing (completed by tester)

To complete the testing for which you have volunteered you will be required to undertake:

Moderate exercise (i.e., exercise that makes you breathe more heavily than you do at rest but not so heavily that you are unable to maintain a conversation) ☐

Vigorous exercise (i.e., exercise that makes you breath so heavily that you are unable to maintain a conversation) ☐

The testing involves:

Walking	☐	Generating or absorbing high forces through your arms	☐
Running	☐	Generating or absorbing high forces through your shoulders	☐
Cycling	☐	Generating or absorbing high forces through your trunk	☐
Rowing	☐	Generating or absorbing high forces through your hips	☐
Swimming	☐	Generating or absorbing high forces through your legs	☐
Jumping	☐		

Section 2: General information

Name: .... Sex: M F Age:

Height (approx.): .... Weight (approx.):

Section 3: Initial considerations

1. Do any of the following apply to you? No Yes

a) I have HIV, Hepatitis A, Hepatitis B or Hepatitis C
b) I am pregnant
c) I have a muscle or joint problem that could be aggravated by the testing described in section 1
d) I am feeling unwell today
e) I have had a fever in the last 7 days

(If you have answered "Yes" to question 1, go straight to section 8)