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Brothers, Robert Matthew, Wearing a Football Helmet Exacerbates Thermal Load During Exercise in Thermoneutral and Hyperthermic Conditions. Masters of Science (Integrative Physiology), December, 2004, 42 pp., 1 table, 4 illustrations, 55 titles in Refrences.

This investigation tested the hypothesis that wearing a football helmet during intense exercise leads to a significant increase in core temperature as indicated by esophageal temperature (T_{es}), head skin temperature (T_h) and heart rate (HR) when compared to a similar bout of exercise performed while no helmet was worn. It was found that in both the helmet and no helmet exercise protocol there was a significant increase in the above variables when compared to baseline. The helmet condition, however, resulted in a significantly greater increase in these variables when compared to the no helmet condition. Furthermore, this effect of the helmet was further increased in a hyperthermic environment when compared to the thermoneutral environment.

WEARING A FOOTBALL HELMET EXACERBATES THERMAL LOAD DURING EXERCISE IN THERMONEUTRAL AND HYPERTHERMIC EXERCISE

Robert Matthew Brothers, B.S.

APPROVED:

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Major Professor

____
Committee Member

____
Committee Member

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University Member

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Chair, Department of Integrative Physiology

____
Dean, Graduate School of Biomedical Sciences

WEARING A FOOTBALL HELMET EXACERBATES THERMAL LOAD DURING EXERCISE IN THERMONEUTRAL AND HYPERTHERMIC CONDITIONS

THESIS

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LIST OF ABBREVIATIONS

SNA	sympathetic nerve activity
VO_2	oxygen uptake
T_c	core temperature
kcal	kilocalorie
T_{es}	esophageal temperature
T_h	head skin temperature
HR	heart rate
ECG	electrocardiogram

CHAPTER I

INTRODUCTION

The human body is a complex set of organs which is capable of adapting to a wide variety of stimuli and environmental conditions. It is constantly exposed to a wide range of external environmental changes such as temperature, humidity, and altitude as well as a variety of internal physiological changes including alterations in pH, blood pressure, osmotic concentration, and internal temperature. Crucial to the homeostatic maintenance of the body is its ability to sense these changes and to respond by making the necessary adaptations. This ability to adapt is especially important when a person begins to undergo any stressful situation including exercise.

During exercise there is an increased oxygen demand of the exercising muscle which is secondary to an increase in tissue oxygen uptake and thus consumption. In an effort to fulfill this increased energy demand there is an increase in respiratory rate which in turn not only increases oxygen uptake but also helps maintain homeostasis by expelling the extra carbon dioxide which is produced as a result of increased oxygen utilization (4,29). In addition there is also a need for an increase in cardiac output which serves to adequately perfuse the exercising muscle and thus provide the necessary oxygen (4,29). The increase in cardiac output is achieved through sympathetically driven increases in both heart rate and myocardial contractility. These adaptive mechanisms help to maintain homeostasis during exercise. The increased sympathetic nerve activity (SNA) results in a wide variety of responses including an increase in heart rate, myocardial contractility, and vasoconstriction. The increases in heart rate and myocardial contractility help to ensure adequate blood flow and thus substrate supply to all organs of the body. The vasoconstriction is an adaptive mechanism to meet the energy demands of the exercising muscles while maintaining an adequate blood pressure. This is achieved by shifting the distribution of cardiac output away from non-essential organs while increasing the blood supply to the exercising muscle. All of these adaptive mechanisms are critical for the maintenance of exercise performance. However, they also present the body with an additional homeostatic challenge (4-6,14,29).

The increases in respiratory frequency, heart rate and myocardial contractility all add to the elevation of metabolically heat production within the body produced by the exercise. In addition the increase in oxygen and metabolic consumption by the exercising muscle also elevates the metabolic heat production. As the amount of metabolically generated heat being produced begins to rise there is a gradual rise in the core temperature (7,11,29-31). In order to maintain exercise performance, as well as to prevent any heat related illnesses the thermoregulatory mechanisms of the body, must also be able to sense and adapt to any rises in core temperature and thus dissipate any extra heat in effort to maintain thermal homeostasis.

In 1966 Saltin and Hermansen were able to elegantly demonstrate the effect that an increase in workload has on thermal balance (31). They showed that during a 60 minute bout of cycle ergometery exercise at workloads of 25%-70% VO_{2max} T_c rose almost linearly with oxygen uptake (31). As previously mentioned, this phenomenon is due to a metabolically-mediated thermal load imposed on the body that is a function of workload and environmental conditions. In order to maintain thermal homeostasis in the face of increased metabolic heat generation there is a redistribution of cardiac output to the skin surface of the periphery (4,11,15,29). This allows for the conductive transfer of heat from the core of the body to the vasculature of the periphery, where heat loss is accomplished via the evaporation of sweat (1,7,11,29,36). During moderate exercise these thermoregulatory responses are able to dissipate most of the heat generated. However as exercise intensity and duration increases, there becomes a point where heat loss can not keep up and therefore heat gain begins to outweigh heat loss thus resulting in a net gain of heat (29). Maximal levels of exercise can generate heat in excess of 1.04×10^5 joules per minute [25 kcal min^{-1}]. Thus, given the typical work efficiency of exercise (22%-25%), a large amount of heat is rapidly produced as workloads approach VO_{2max}. As a result, the highest rates of elevation in heat gain have been estimated to range from 0.15°C to 0.25°C min^{-1} (19-20,22). This effect of increasing core temperatures during heavy exercise not only impairs exercise performance (2,12,25,34) but also increases the risk of heat-related injuries (10,16-17).

Any increase in environmental temperature will also add a burden to the thermoregulatory responses of the body and this added thermoregulatory stress will become progressively more cumbersome as exercise intensity and duration increases. As already described, the body relies on the conductive transfer of metabolically generated heat from the core of the body to the cutaneous vasculature of the periphery in order to dissipate this heat via the evaporation of sweat (1,7,11,29,36). During intense exercise, skin temperatures gradually begin to rise and this effect is greatly increased as environmental temperature becomes warmer. This, in turn, reduces the temperature gradient between the core of the body and the periphery. Likewise, sweat production increases with increases in both exercise intensity and environmental temperature (7,29). The increase in skin temperature that occurs during hyperthermic exercise places an increased demand on the cardiovascular system in attempt to maintain a balance between active muscular tissue perfusion and heat dissipation via cutaneous perfusion. This is further accentuated by the loss of blood volume due to the loss of fluids through sweat evaporation which will eventually lead to peripheral vasoconstriction and thus further limits the thermoregulatory potential of the body during intense hyperthermic exercise (11).

In recent years, heat-related illness and injuries have gained more and more attention in areas such as industrial, military, and athletic-related research (9,23,24,34). More attention and effort is spent on gaining a better understanding of the thermoregulatory mechanisms of the body and the many environmental factors that may alter the effectiveness of these mechanisms. A better understanding of these issues will provide employees, employers, players, coaches, trainers and physicians an opportunity to achieve optimal performances at work or competition as well as to generate a better foundation of knowledge to prevent and treat any heat related injuries that may occur. One area of thermoregulation that has been the target of attention involves the potential limitations that clothing and equipment imposes on the heat dissipating ability of the body (13,17,20,21,26). The idea is that while certain clothes and equipment may be necessary as a means of protection during various tasks; they may however offer a disadvantage from a heat dissipating standpoint (8,9,17,20,26). Helmets, pads, hats, long sleeves all serve beneficial protective roles, however they limit heat dissipation in several ways including decreasing the heat gradient between the core and the periphery, limiting the available area for evaporation of sweat, and limiting the body surface area that is exposed to the environment and thus convective cooling via circulating air and evaporation of sweat (8,9,17). Clothing and protective equipment also add additional weight. This additional weight can increase the effort that is needed to achieve any given task which increases the amount of metabolically generated heat that is produced thus further exposing the body to a potentially dangerous environment (9,8,17,20,26). Several methods have been used to reduce the thermoregulatory strain that is induced by work and exercise. Some of these methods include pre-exercise cooling (19-20,23,33), modes of post-exercise cool-down (8), effects of various levels of hydration status (28,32), effects of various supplements (3,27), and effects of various equipment and uniforms (9,13,17,20,26).

The head has become a major focus in regards to thermoregulation (13,23,25,26,27). It contains a high density of cutaneous microvasculature and has limited vasoconstricting potential and therefore provides a large surface area with a great heat loss capacity (23,27-28). Thus, the head serves as a crucial site for heat dissipation at rest and becoming progressively more important during exercise, accounting for up to

50% of total heat dissipation (23,27-28). Therefore sports or other areas of work in which head gear is worn, such as the military and fire fighters may limit one's ability to optimally dissipate heat.

Football players are some of the most susceptible individuals to heat-related illnesses and injuries. The equipment that is worn during football games and practices not only adds additional weight to the player but it also limits the heat dissipating mechanisms. This is mainly due to the fact that the equipment covers a large portion of the body and thus prevents evaporative heat loss, but also because it helps to increase the temperature of the skin beneath the uniform and thus decreases the heat gradient between the core and the periphery thus limiting the conductive and convective transfer of heat away from the skin surfaces (17,20). Additionally, the beginning of the football season usually occurs in the summer months when environmental conditions are generally at their hottest and most humid levels (17,20). This leads to an added heat burden and associated occurrence of heat-related injuries at all levels of competitive football (17,20). In the years between 1995 and 2002 there were 29 recorded heat-related deaths in American Football between high school, collegiate, and professional athletes. Although this is a disturbing statistic it is an underestimation of the severity of the problem, because it does not account for other heat related symptoms including dehydration, cramps, headaches, dizziness, and stroke. We hypothesize that this is, in part, due to impaired thermoregulation from football headgear and that these effects are further exacerbated in a hyperthermic environment that is characteristic of most early season football games and practices. Therefore, this study was designed as an investigation of the effect of a standard collegiate football helmet on thermoregulation in thermoneutral environments during intermittent intense exercise as occurs during football games and practices.

The specific aims of the proposed project are as follows:

While it is well understood that exercise produces metabolically generated heat and that this heat generation becomes progressively greater as workload intensity and duration increases, the thermoregulatory effect of wearing protective equipment, especially a football helmet is still unclear.

Hypothesis #1:

Esophageal temperature, (T_{es}), head skin temperature (T_h) and heart rate (HR) would increase significantly from baseline values during a 25 minute exercise bout on a treadmill due to metabolically generated heat.

Hypothesis #2:

The T_{es}, T_h, and HR response to intermittent treadmill sprinting at the speed which elicited each subjects respective VO_{2max} would be significantly greater when the football helmet was worn when compared to the no helmet protocol, due to an inhibitory effect on the heat-loss mechanisms of the body imposed by the helmet.

Hypothesis #3:

The rate of return in T_{es}, T_h, and HR to baseline values during the active cool-down period would be significantly slower during the helmet protocol when compared to the no helmet protocol, due to an inhibitory effect on the heat-loss mechanisms of the body imposed by the helmet.

Significance:

The studies attempted from the proposed studies will further our understanding of the thermoregulatory mechanisms of the human body during intense thermoneutral exercise. Many investigations have studied thermoregulation during exercise, however the effects of protective equipment, especially the wearing of football helmets football helmets, is still not fully understood. The results will help to give a quantitative measure of the thermal strain imposed by football helmets which will be especially helpful to provide players, coaches, trainers, and physicians an opportunity to achieve optimal performances at work and/or competition as well as to generate a better foundation of knowledge to prevent and treat any heat related injuries that may occur

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CHAPTER II

MANUSCRIPT

WEARING A FOOTBALL HELMET EXARCERBATES THERMAL LOAD DURING THERMONEUTRAL EXERCISE

Abstract

The aim of the present investigation was to test the hypothesis of whether wearing a football helmet alters thermoregulation and cardiovascular responses during exercise in a thermoneutral environment. Eight subjects (21-30 years old) performed 25 min of exercise in ambient conditions, ~75°C and ~45% relative humidity. The protocol included a 5 min warm-up at 4.5 mph, 15 min of intermittent treadmill sprinting at a speed and grade eliciting their respective maximal oxygen uptake, VO2max, followed by a 5 minute active cool-down period at 3.0 mph, on a treadmill with a 2 % grade. Four skin thermistors were placed on the head to measure head temperature (T_h), an esophageal probe was inserted to measure core temperature (T_c), and an electrocardiogram recorded heart rate (HR). The protocol was performed on consecutive days: one day the subject wore a standard collegiate helmet and the other without the helmet in a counterbalanced randomized order. We demonstrated that T_c increased in both protocols ($P<0.05$) and remained significantly elevated throughout the remainder of the protocol. T_h was 0.88°C higher at baseline, 1.36°C higher at min 20, and 1.47°C higher at the end of the protocol when the helmet was worn as compared to the no helmet condition ($p<0.05$). HR increased under both conditions ($P<0.05$), and was greater ($P<0.05$) with the helmet from minute 9 of the protocol until completion of the cool-down period. These data demonstrate that wearing a football helmet in thermoneutral conditions rapidly augments the thermal load produced by 15 min of intensive intermittent exercise leading to significant increases in T_c, T_h and HR.

Key Words: *core temperature, ambient temperature, intermittent sprinting, football helmet*

Introduction

Exercise produces a metabolically-mediated thermal load that is a function of workload and environmental conditions. The maintenance of thermal homeostasis depends on one's ability to balance heat gain with heat loss. Rates of energy expenditure during high intensity exercise can be in excess of 1.04 $\times 10^5$ joules per minute [25 kcal min $\times^{-1}$]; thus, given the typical efficiency of exercise, a large amount of heat is produced rapidly at high workloads. As a result, the highest rates of elevation in heat gain have been estimated to range from 0.2 to 0.3 °C min^{-1} (9,10). Within limits, the body is able to maintain a balance between the amount of heat generated and the amount of heat dissipated; however, as heat generation increases there is a gradual rise in the heat stored internally which leads to an increase in T_c (12). This effect of exercise on heat stores of the body can impair performance and increase the risk of heat-related injuries.

The performance of an athlete is affected by many factors including elevation of body temperature. An athlete's core temperature begins to rise shortly after the onset of intense exercise. As the core temperature continues to rise, a critical temperature is reached at which optimal performance of the athlete can be limited (7). The primary methods of heat dissipation during exercise require evaporation of sweat and the convective transfer of heat from the body core to the skin by redistribution of the cardiac output to the cutaneous vasculature (15). The head, because it contains a high density of cutaneous vasculature and has limited vasoconstricting potential, is normally slightly warmer than all other parts of the body and provides a large surface area with a great heat loss capacity (2,3,14,19). Thus, the head is a crucial site of heat dissipation both during rest and exercise, accounting for up to 50 % of total heat dissipation (12-14,19). Therefore, sports in which headgear is worn, such as football, may limit one's ability to dissipate heat. Importantly, the beginning of the football season usually occurs in the summer months when environmental conditions are generally at their hottest and most humid levels (5,6). This leads to an added heat burden and associated occurrence of heat-related injuries at all levels of competitive football (5,6). We hypothesize that this is, in part, due to impaired thermoregulation resulting from football headgear. This study was designed as an initial investigation of the effect of a standard football helmet on thermoregulation in a thermoneutral environment during intermittent intense exercise as occurs during football games and practices.

Methods

Subjects. A total of eight subjects (three female) were recruited from the UNT Health Science Center and other local universities. Subject statistics are summarized as follows (mean±SE): age = 25.4±1.3 yrs; weight = 75.8±4.6 kg; height = 175.8±2.6 cm, VO_{2max} = 4.2±0.23 l/min. All subjects provided written consent approved by the University of North Texas Health Science Center Institutional Review Board for the use of Human Subjects. Prior to the experiment, all subjects completed a medical history questionnaire, resting ECG and a graded treadmill test to assess for ECG abnormalities, to determine maximal HR and to determine the speed at which VO_2 max was elicited. All subjects were healthy non-smokers and none were taking prescription medication.

Graded Exercise Test. On the first visit to the lab, each subject performed a graded treadmill exercise test for the determination of a maximum workload and maximal oxygen uptake during treadmill exercise. The graded exercise test used a treadmill protocol beginning at three and one-half mph and a 2% grade, followed by speed increases of one-half mph/min. The exercise test was terminated when the subject reached volitional fatigue and voluntarily quit.

The VO_2max was determined during the graded exercise test by having the subjects respire through a mouth piece attached to a low-resistance turbine volume transducer (Sensor Medics VMM E-2A, Anaheim, CA) for measurement of ventilation volumes. Respiratory gases were continuously sampled from the mouthpiece for determinations of fractional concentrations of O_2, CO_2, and N_2 by mass spectrometry (Perkin-Elmer MGA1100B, St. Louis, MO). The analog signals of the mass spectrometer were subjected to analog-to-digital conversion and computer analysis (Dell OptiPlex GXi) for on-line, breath-by-breath determination of respiratory gases. Heart rate was continuously recorded throughout the VO_2 max test and the experimental protocols using a three lead ECG.

Experimental Design. Subjects were studied twice, once each on consecutive days at the same time of day. Subjects wore the same light exercise attire on both days of the experiment consisting of exercise shorts, t-shirt, and running shoes. On one day, a standard collegiate football helmet was worn, while on the other no headgear was worn. The order was randomized and counterbalanced.

Experimental Protocol. Each test began with the subject warming up on the treadmill at 4½ mph and 2% grade for five minutes. The speed of the treadmill was then raised to the speed at which VO_2 max was elicited for the respective subject, (the average speed was 8.2 mph). The subject then performed 15 minutes of intermittent exercise (altering 30 sec on and 30 sec off). This was followed by an active cool-down period in which the subject walked at a speed of 3½ mph and 2% grade.

Measurements. Heart Rate: Heart Rate (HR) was continuously monitored throughout the protocol with a standard lead II electrocardiogram (ECG).

Esophageal Temperature: Esophageal Temperature (T_{es}) was recorded as an index of core temperature once each minute throughout the experimental protocols using an esophageal probe (YSI 4491E Probe, Yellow Springs Instruments, Yellow Springs, OH) connected to a model 8502-12 digital thermometer (Cole Parmer Instrument Co., Vernon Hills, IL). The probe was inserted nasally to a length equal to 25% of the height of the subject (8,11). The location of the probe was then determined by having the subject talk after insertion to ensure that the probe went down the esophagus and not the trachea.

Head Skin Temperature: Head Skin Temperature (T_h) was recorded once each minute throughout the experimental protocols as an average of four skin thermistors (YSI 409B Probe). One probe was placed at the center of the forehead, one on the right temple, one on the back of the neck where the lower portion of helmet ends, and one on the top of the head.

Data Analysis: Baseline values of T_c, T_h, and HR were obtained for one minute prior to the onset of the protocol. These values were then recorded throughout the exercise and recovery periods as noted above.

Analyses: A two way repeated measures ANOVA was used to compare T_{es}, T_h, and HR at different time points as well as between experimental protocols. Where F values revealed significant main effect differences, a *post hoc* analysis was performed to determine specific time point differences using a Tukey multiple range test. The linear slopes of the recovery data were compared between conditions with a paired T test. P values < 0.05 were considered significant. All results are presented as mean (±SE).

Results

Subjects. The demographics and physiological measures of the eight volunteer subjects are presented in Table 1.

Table 1. Subject Characteristics

	(N=8)
Age, years	25.4 ± 1.3
Height, cm	175.8 ± 2.6
Weight, kg	75.8 ± 4.6
Peak 0_2 Uptake, ml/min	4.2 ± 0.231

T_{es} responses during 30 minute exercise protocol. The data in Figure 1 illustrate that T_{es} was significantly different from baseline values in both conditions ($p < 0.05$ at min 4 with helmet, $p < 0.05$ at min 5 without helmet) and remained elevated for the duration of the protocol under both conditions. The helmet condition elicited a greater increase in T_{es} when compared to the no helmet condition ($p < 0.05$ at min 9) and remained significantly different for the duration of the protocol. The rate of recovery toward baseline T_{es} values was decreased in the helmet condition ($p < 0.05$; figure 1).

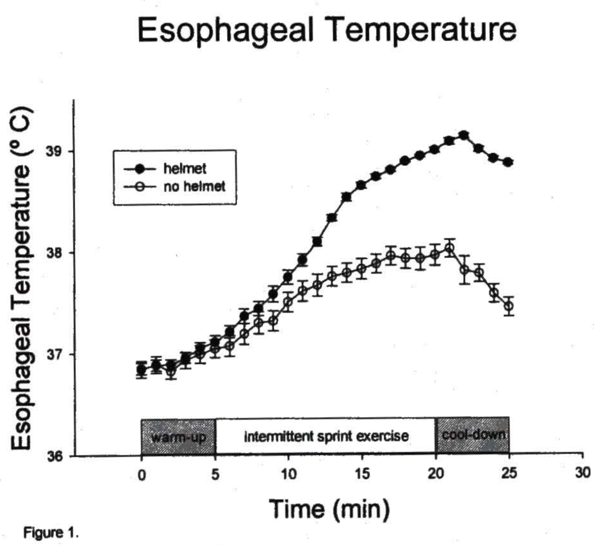

FIGURE 1. Esophageal Temperature during warm-up (min 1-5), Exercise (min 6-20) and Recovery (21-25). T_{es} increased significantly above *baseline* from min 4-25 (with helmet) and min 5-25 (without helmet). T_{es} was significantly higher with the helmet from min 9-25, when compared to no helmet ($P < 0.05$) ($N = 8$).

HR responses during 30 minute exercise protocol. The data in Figure 2 illustrate that HR was significantly different from baseline values in both conditions at the onset of the protocol ($p < 0.05$ at min 1 in both conditions). The helmet condition elicited a greater increase in HR when compared to the no helmet condition ($p < 0.05$ at min 9) and remained significantly greater for the duration of the protocol. The last five minutes of the protocol (recovery) show that the rate of recovery toward baseline HR values was significantly decreased in the helmet condition such that HR remained significantly elevated at the end of the protocol with the helmet (Figure 2).

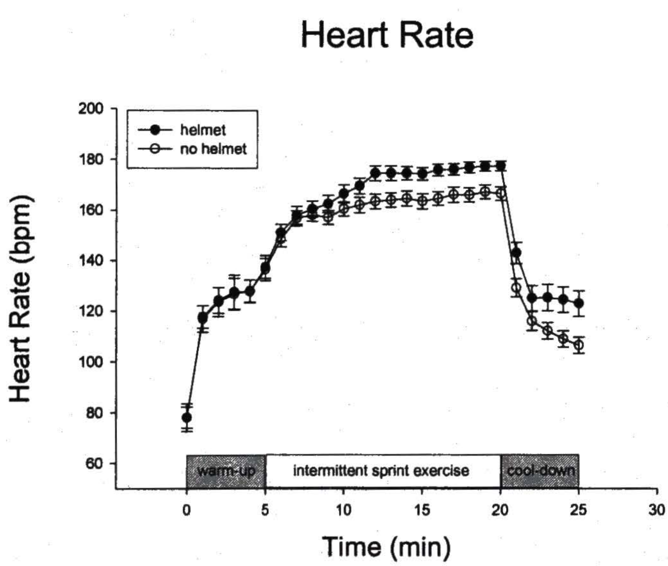

Figure 2.

FIGURE 2. Heart Rate during warm-up (min 1-5), Exercise (min 6-20) and Recovery (21-25). HR was increased significantly above baseline from min 1-25 (both conditions). HR was significantly higher with the helmet from min 12-25, when compared to the no helmet ($P < 0.05$) ($N = 8$).

T_h responses during 30 minute exercise protocol. The data in Figure 3 illustrate that T_h was significantly different from baseline values in both conditions ($p < 0.05$ at min 7 with helmet, $p < 0.05$ at min 8 without helmet) and remained significantly different for the duration of the protocol. The helmet condition elicited a greater increase in T_h when

compared to the no helmet condition at the onset of the protocol and remained significantly different for the duration of the protocol (p < 0.05 at baseline).

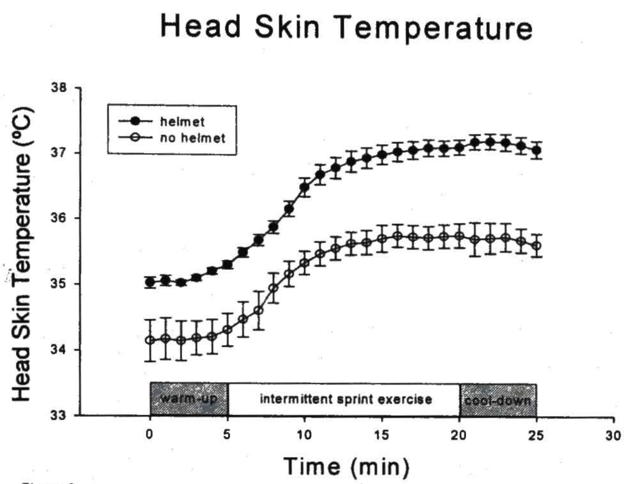

Figure 3.

FIGURE 3. Head Temperature during warm-up (min 1-5), Exercise (min 6-20) and Recovery (21-25). T_h increased significantly above baseline from min 7-25 (helmet) and min 8-25 (without helmet). T_h was significantly higher with the helmet from min 1-25 when compared to no helmet ($P < 0.05$) ($N = 8$).

T_{es} responses at different phases of the 30 minute exercise protocol. The data in Figure 4 illustrate the difference in the increases in T_{es} from baseline in the two experimental conditions experimental conditions at different phases of the exercise protocol as well as the peak change measured from the maximal T_{es} value recorded in both conditions. The helmet condition elicited significant increases ($p<0.05$) in T_{es} from baseline both at the end of intermittent sprinting (min 20) and at the end of the recovery period (min 25).

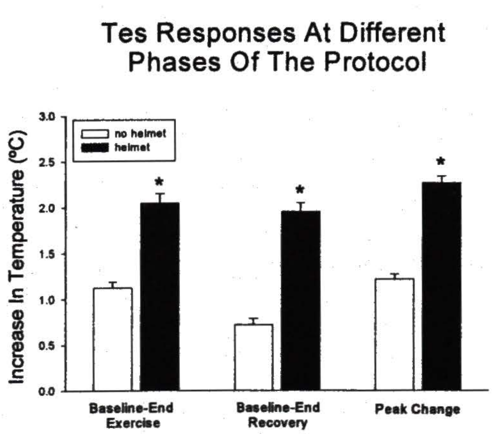

Figure 4.

FIGURE 4. Increases in esophageal temperature from baseline to the end of the intermittent sprinting (min 20), end of recovery (min 25) phases of the protocol and the peak change in T_{es}; * significantly different between conditions ($P < 0.05$) ($N = 8$).

Discussion

The present study was designed to determine the thermoregulatory effects of wearing a football helmet during 15 minutes of intermittent intense exercise in a thermoneutral environment. The limited amount of previous research on the thermoregulatory load of football equipment has focused on the uniform as a whole (5,6). Although the results show an increased thermoregulatory load to the subjects, we hypothesized that the helmet was a major contributor to the increased thermal load seen during football practice or games. This is the first study to observe the effects of wearing a football helmet while performing intermittent intense exercise. The intermittent sprint phase of the protocol was set at 30 sec. on and 30 sec. off at 100% VO_2 max in an effort to partially mimic the duration and intensity that is performed during football practices and games.

As exercise duration and intensities increase, the amount of metabolically generated heat produced in the body gradually overwhelms the thermoregulatory mechanisms of the body that act to dissipate the heat produced. This results in a net heat gain, thus leading to increases in T_c (15). If not properly monitored, increases in T_c can lead to a variety of consequences including decreased exercise performance, cramps, heat exhaustion, heat stroke, and in some cases, death (5).

The finding in our study that wearing a football helmet during exercise induces increases in T_c and HR that remains elevated during recovery agrees with results from another study in which the thermoregulatory responses wearing an entire football uniform were studied (6). However, in this study the effects of the football helmet alone were not considered. The subjects performed 3 separate 30 minute trials of steady state exercise at 9.6 km/hr (~6 mph) for 30 minutes, followed by a 30 minute recovery period, one trial while wearing shorts only, one while wearing a full football uniform, and one while wearing shorts and a backpack weighing the same amount as a football uniform. Although there are differences in experimental protocols, the findings by Mathews *et al.* (6) that T_c and heart rate were significantly elevated in both the uniform and the backpack protocol when compared to control values are consistent with our findings.

Another study that looked at thermoregulatory responses to exercise with and without headgear is also in agreement with our findings. Rasch and Cabanac (13) demonstrated that the heat loss values from the head were significantly lower while wearing a wool-cap during braked cycle ergometric exercise at exercise loads of 50-150 W for 30 minutes when compared to control values obtained when the same protocol was performed without a hat. Although this study did not look at the results during a recovery time period it is clear that wearing a wool-cap during exercise significantly impairs thermoregulatory responses during exercise.

Our results differ somewhat from results obtained by Moore-Sheffield *et al.* (11), where they found that wearing a cycling helmet did not alter T_{es} during 90 minutes of cycling at 60 % VO_2 max. They also reported that wearing a cycling helmet resulted in no significant changes in T_h. Another study (2) using cycling helmets while exercising at 70% VO_2 max with a 6 to 7 miles/h wind directed towards the face showed no occurrence of additional thermoregulatory load induced by wearing a cycling helmet. The exercise, use of simulated wind, as well as the design of the helmet likely explains the discrepancies between these studies. In addition, the rate of heat production during low intensity exercise (60-70% VO_2 max) is much lower than during the intermittent maximal exercise we used; thus, the reliance on heat dissipation via the head was probably much lower. Furthermore, the 6-7 miles/h wind speed directed at the subject's face would enhance convective heat loss. In addition the helmet design of the cycling helmets, which offers more ventilatory potential (2) than the heavily padded and closed football helmet, can also be the reason for the differences in heat loss potential.

Although the duration of our recovery phase of the protocol was fairly short, a major finding in this study is that wearing a football helmet significantly limits the amount of heat dissipated during a five minute active cool-down. Our results show that at the end of recovery, T_c remained more than one degree higher with the helmet (figures 1 and 4). This difference between the two protocols at the end of recovery is not only seen as an increase in T_c and associated increase in T_h, but also directly leads to a significant increase in cardiovascular stress between the two protocols; specifically heart rates remained higher in the helmet condition (Figure 2). Several other studies have assessed T_{es} during recovery from exercise of similar durations and intensities and found that T_{es} returned toward baseline values at rates similar to our control condition (no helmet) (1,4,6,16-18). In these studies, the range of increase in T_{es} was 0.5°C to 1.4°C (compared to 1.1°C in the present study) and the range of decrease from end exercise T_{es} values was from 0.2°C to 0.4°C (compared to 0.4°C in the control condition of this study). The rate of decline in T_{es} was considerably slower in the helmet protocol of the present study when compared to the no helmet control condition; thus the helmet created a significant thermal load that persisted after exercise was stopped.

During intense exercise the primary means of heat dissipation by the body is through evaporation of sweat. However maximal sweat rates during exercise have been shown to be 30 ml/min which results in 7.53×10^4 joules [18 kcal] of heat dissipated per minute (11). At the same time maximal exercise has been shown to produce approximately 8.1×10^4 joules [19-20 kcal] of heat (11). This means that at high workloads heat loss does not keep pace with heat production and thus a net heat gain can occur at rates of up to 1.0°C per 5 minutes at maximal exercise (9,10).

In conclusion, these data demonstrate that wearing a football helmet significantly impairs heat loss, thereby, resulting in an increased net thermal load on the body during intense exercise under thermoneutral conditions. It is logical that this effect is more severe when environmental temperatures and humidity are extreme.

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CHAPTER III

CONCLUSION AND FUTURE RESEARCH

Throughout these studies we were able to demonstrate the thermoregulatory and cardiovascular consequences of exercising on a treadmill while wearing a standard collegiate football helmet. We measured the heart rate (HR) responses, head skin temperature (T_h), responses, and esophageal temperature (T_{es}) responses to an intermittent bout of intense sprint exercise at each subjects' respective VO_{2max} workload. We were able to demonstrate in quantifiable terms the extent of thermoregulatory and cardiovascular strain that is caused by exercising in a thermoneutral environment while wearing a football helmet. HR, T_h, and T_{es} were all significantly higher during the bout of exercise when the helmet was worn as compared to when the helmet was not worn. Further these responses all remained significantly higher during the proceeding five minute active recovery period when the helmet was worn. These findings have led to the following conclusions:

1) The football helmet leads to an in crease in core temperature, partially as a result of limiting the heat dissipating abilities of the head. As described earlier the head is a crucial site of heat loss during exercise.

2) The football helmet leads to an increase in cardiovascular strain during exercise. This function could be two-fold. First the increase in core

3) temperature would result in an increase in peripheral blood flow in effort to dissipate heat. This would in turn cause a greater demand on the heart as it is forced to spread out the cardiac output over a greater area. Secondly the added weight and potential discomfort of the helmet could result in an additional strain that would affect the work of the heart.

Future Research:

With the present research we were able to demonstrate the thermoregulatory and cardiovascular affects of wearing a football helmet during exercise. However there are still many questions that remain to be answered to fully determine the affects. The following is a list of suggestions for future research:

1) Attempt to apply these concepts to more realistic football settings. This would involve a more in depth understanding of the duration and intensity of typical football plays, practices, and games.
2) Investigate the effect of body mass on the thermoregulatory and cardiovascular responses; i.e. how to the responses of lineman and backs differ.
3) Investigate the effects of hydration status on these responses.
4) Investigate the effect of the additional weight that is created by the football helmet. For example are the effects created by the limitations in heat dissipation or are they due to the additional weight of the helmet.

5) Investigate the effects of the helmet when compared to the rest of a standard football uniform.
6) Investigate the effects of pre-exercise precautions on the thermoregulatory effects of wearing a football helmet. For example is this thermoregulatory effect diminished with pre-exercise cooling.

FIGURE AND TABLE LEGENDS

TABLE 1. Averages of subject characteristics. Age (yrs), height (cm), weight (kg), and peak oxygen uptake (ml/min).

FIGURE 1. Esophageal Temperature during warm-up (min 1-5), Exercise (min 6-20) and Recovery (21-25). T_{es} increased significantly above *baseline* from min 4-25 (with helmet) and min 5-25 (without helmet). T_{es} was significantly higher with the helmet from min 9-25, when compared to no helmet ($P < 0.05$) ($N = 8$).

FIGURE 2. Heart Rate during warm-up (min 1-5), Exercise (min 6-20) and Recovery (21-25). HR was increased significantly above baseline from min 1-25 (both conditions). HR was significantly higher with the helmet from min 12-25, when compared to the no helmet ($P < 0.05$) ($N = 8$).

FIGURE 3. Head Temperature during warm-up (min 1-5), Exercise (min 6-20) and Recovery (21-25). T_h increased significantly above baseline from min 7-25 (helmet) and

min 8-25 (without helmet). T_h was significantly higher with the helmet from min 1-25 when compared to no helmet ($P < 0.05$) ($N = 8$).

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FIGURE 4. Increases in esophageal temperature from baseline to the end of the intermittent sprinting (min 20), end of recovery (min 25) phases of the protocol and the peak change in T_{es}; * significantly different between conditions ($P < 0.05$) ($N = 8$).

Table 1. Subject Characteristics

	(N=8)
Age, years	25.4 ± 1.3
Height, cm	175.8 ± 2.6
Weight, kg	75.8 ± 4.6
Peak 0_2 Uptake, ml/min	4.2 ± 0.231

Values of subject characteristics ± SE

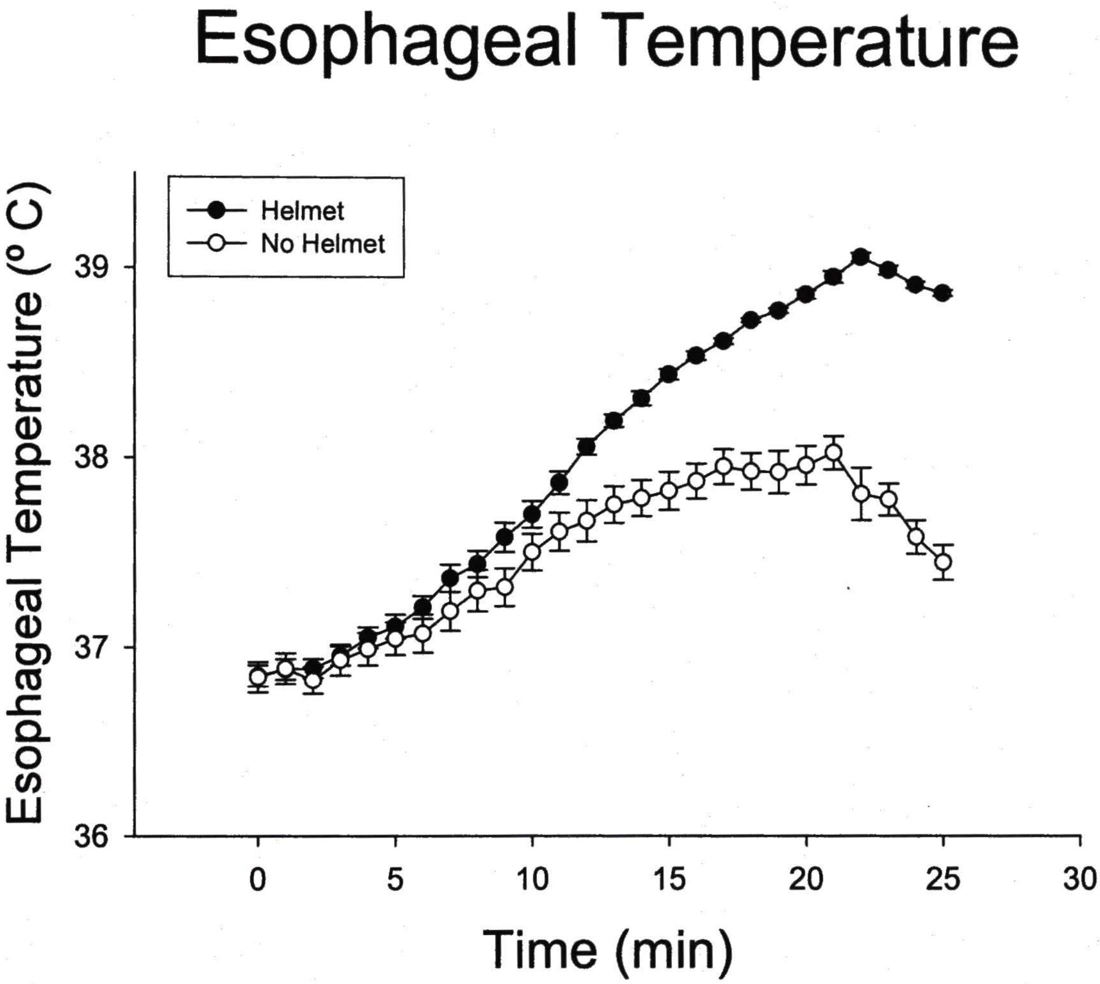

Esophageal Temperature
Helmet
No Helmet
Esophageal Temperature (° C)
39
38
37
36
0
5
10
15
20
25
30
Time (min)

Figure #1

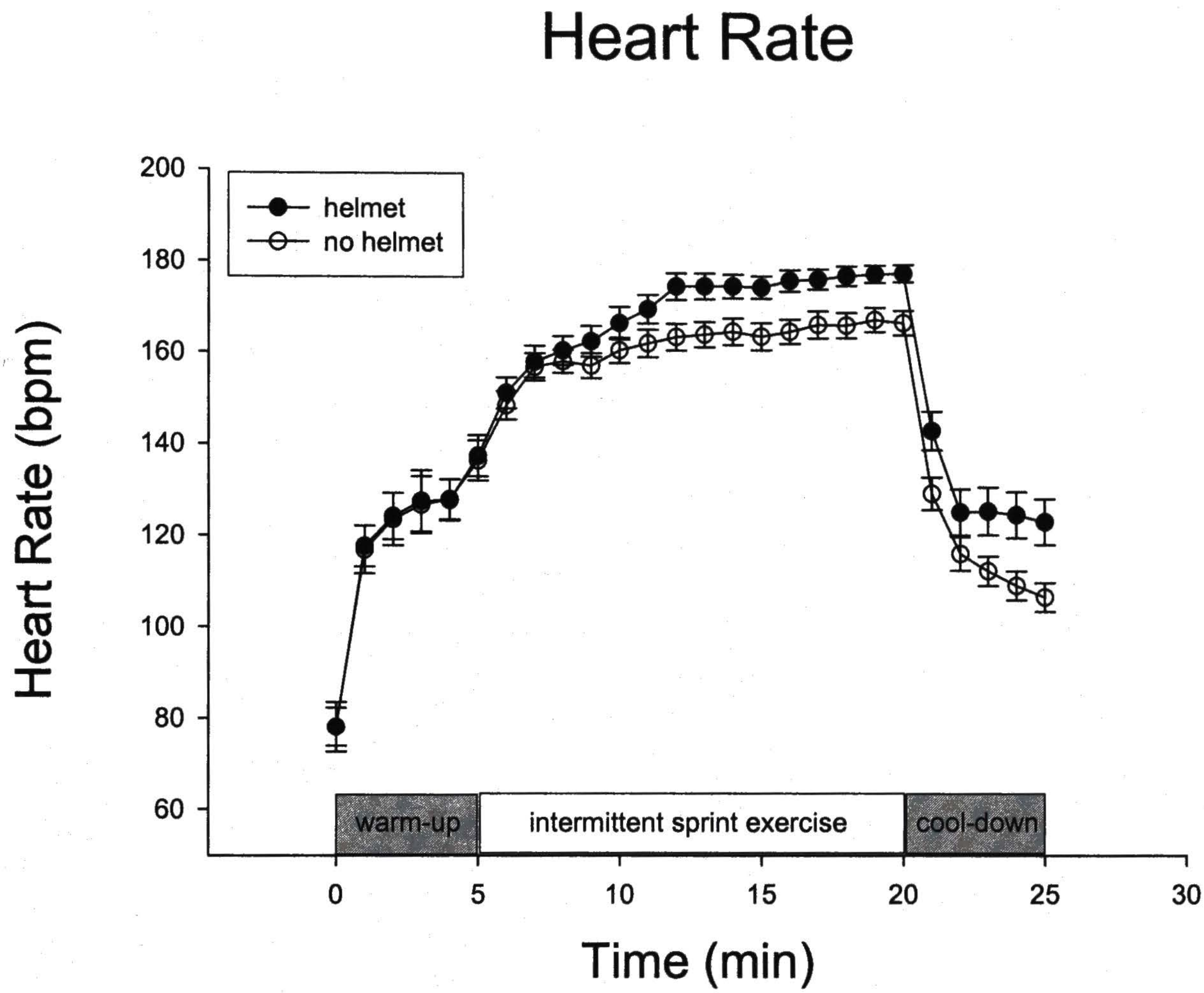
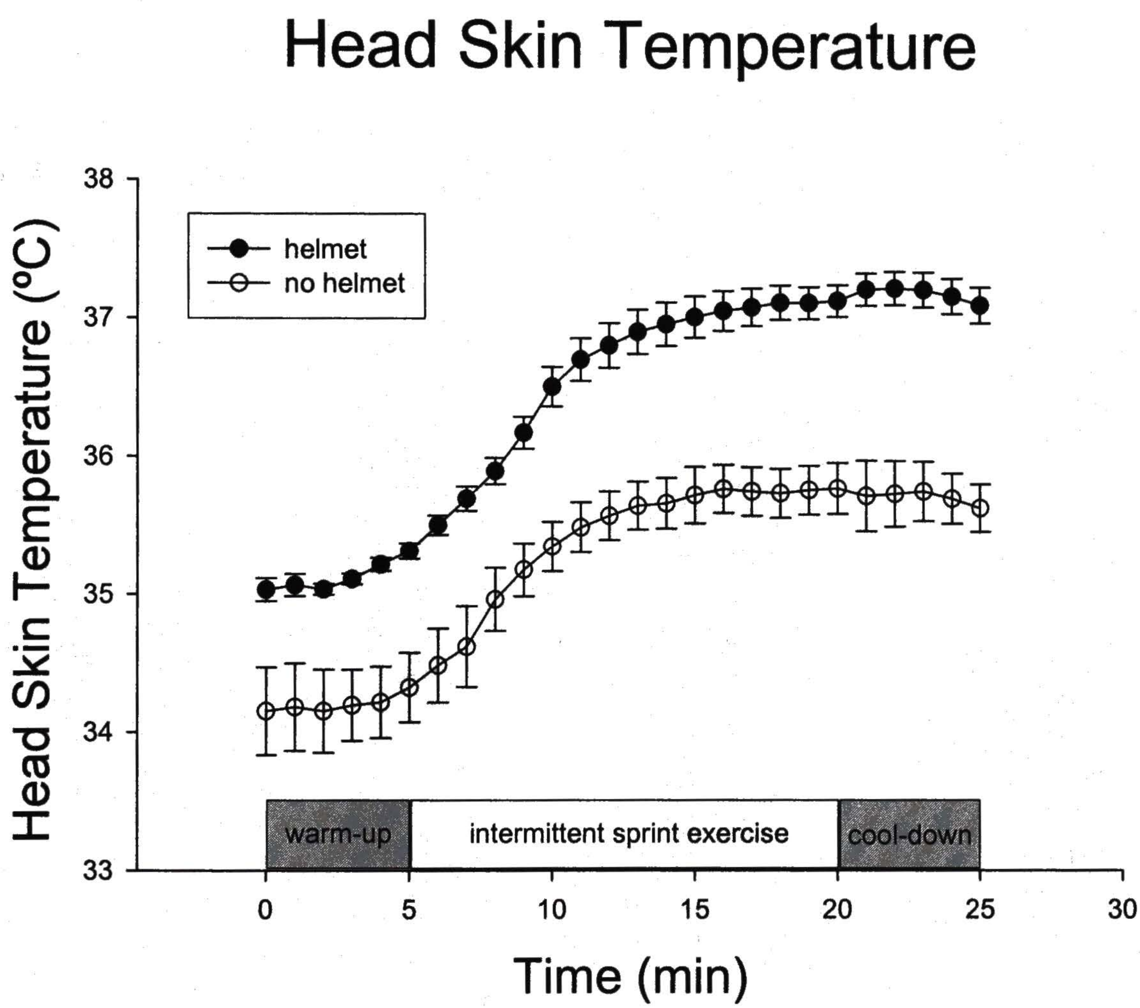

Heart Rate
helmet
no helmet
200
180
160
140
120
100
80
60
Heart Rate (bpm)
warm-up
intermittent sprint exercise
cool-down
0
5
10
15
20
25
30
Time (min)

Figure 2.



Head Skin Temperature
Head Skin Temperature (ºC)
38
37
36
35
34
33
helmet
no helmet
warm-up
intermittent sprint exercise
cool-down
0
5
10
15
20
25
30
Time (min)

Figure 3.

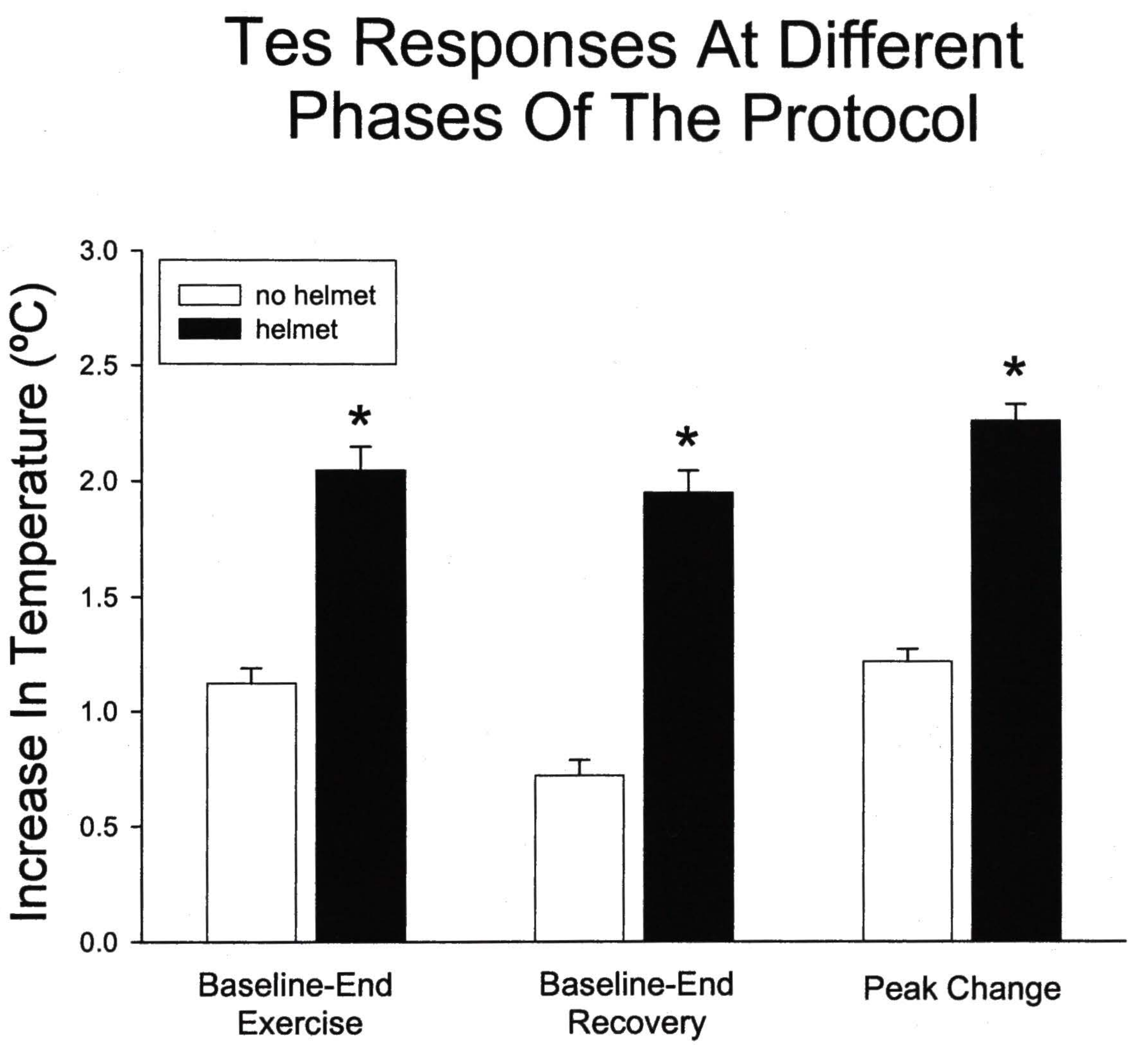

Tes Responses At Different
Phases Of The Protocol
Increase In Temperature (ºC)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
no helmet
helmet
*
*
*
Baseline-End
Exercise
Baseline-End
Recovery
Peak Change

Figure 4.